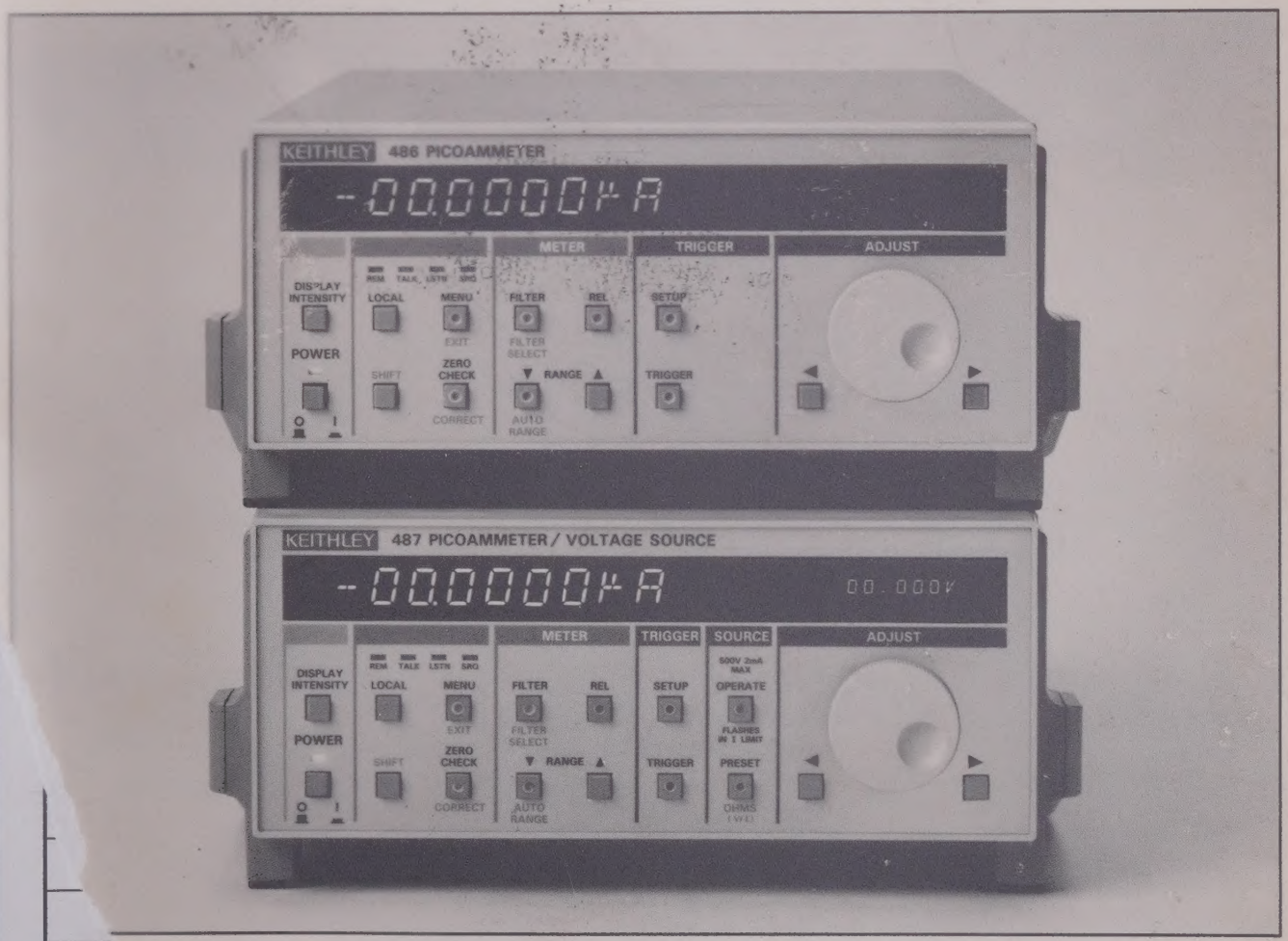
KEITHLEY INSTRUMENTS

Model 486 Picoammeter and Model 487 Picoammeter/Voltage Source Instruction Manual



Contains Operating and Servicing Information

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Instruction Manual
Model 486 Picoammeter
Model 487 Picoammeter/Voltage Source

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SAFETY WARNINGS

The following precautions should be observed before using Model 486/487. Refer to main manual for detailed safety information and complete operating instructions.

The Model 486/487 is intended for use by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read over the instruction manual carefully before using the instrument.

Before operating the instrument, make sure the line cord is connected to a properly grounded power receptacle.

Exercise extreme caution when a shock hazard is present. Lethal voltages may be present on the test fixture or the Model 487 output jacks. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30V RMS or 42.4V peak are present. **A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.**

Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

For maximum safety, do not touch the Model 487 connections, test fixture, test cables or connections to any other instruments while power is applied to the circuit under test. Turn off all power and discharge all capacitors before connecting or disconnecting cables or jumpers. Also, keep the test fixture lid closed while power is applied to the device under test. Safe operation requires the use of the lid interlock.

Do not touch any object which could provide a current path to the common side of the circuit under test or power line (earth) ground.

Do not exceed the maximum signal levels of the instrument, as shown on the rear panel and as defined in the specifications and operation section of the instruction manual.

Connect the ⏚ screw of the test fixture to safety earth ground using #18 AWG or larger wire.

Instrumentation and accessories should not be connected to humans.

Maintenance should only be performed by qualified service personnel. Before performing any maintenance, disconnect the line cord and all test cables from the instrument.

CONTROL SUMMARY

DISPLAY INTENSITY: Selects normal/dim/off display.

LOCAL: Places unit in local and restores front panel key operation.

MENU: Use with the knob or cursor keys to configure the following menu items; data store, data recall, I-limit (Model 487), integration, IEEE-488 bus (bus or talk-only), defaults, selftest, debug, calibrate, and V-Source calibrate (Model 487 only).

SHIFT EXIT: Exits MENU or trigger SETUP.

ZERO CHECK: Allows check of offsets, and must be disabled to obtain an input signal measurement.

SHIFT CORRECT: Performs automatic zero correction to null instrument offsets.

FILTER: Enables or disables the selected filter(s).

SHIFT FILTER SELECT: Use with knob or cursor to select the filter(s); digital, analog, or digital + analog.

REL: Use to establish a baseline using the displayed reading.

▼ *RANGE* ▲: Use range keys to select a lower or higher current range.

SHIFT AUTO RANGE: Use to enable/disable autorange.

SETUP: Use with knob or cursor keys to configure the following trigger setup items; trigger mode, trigger interval, trigger delay, and trigger source.

OPERATE: Places V-Source of Model 487 in operate or standby.

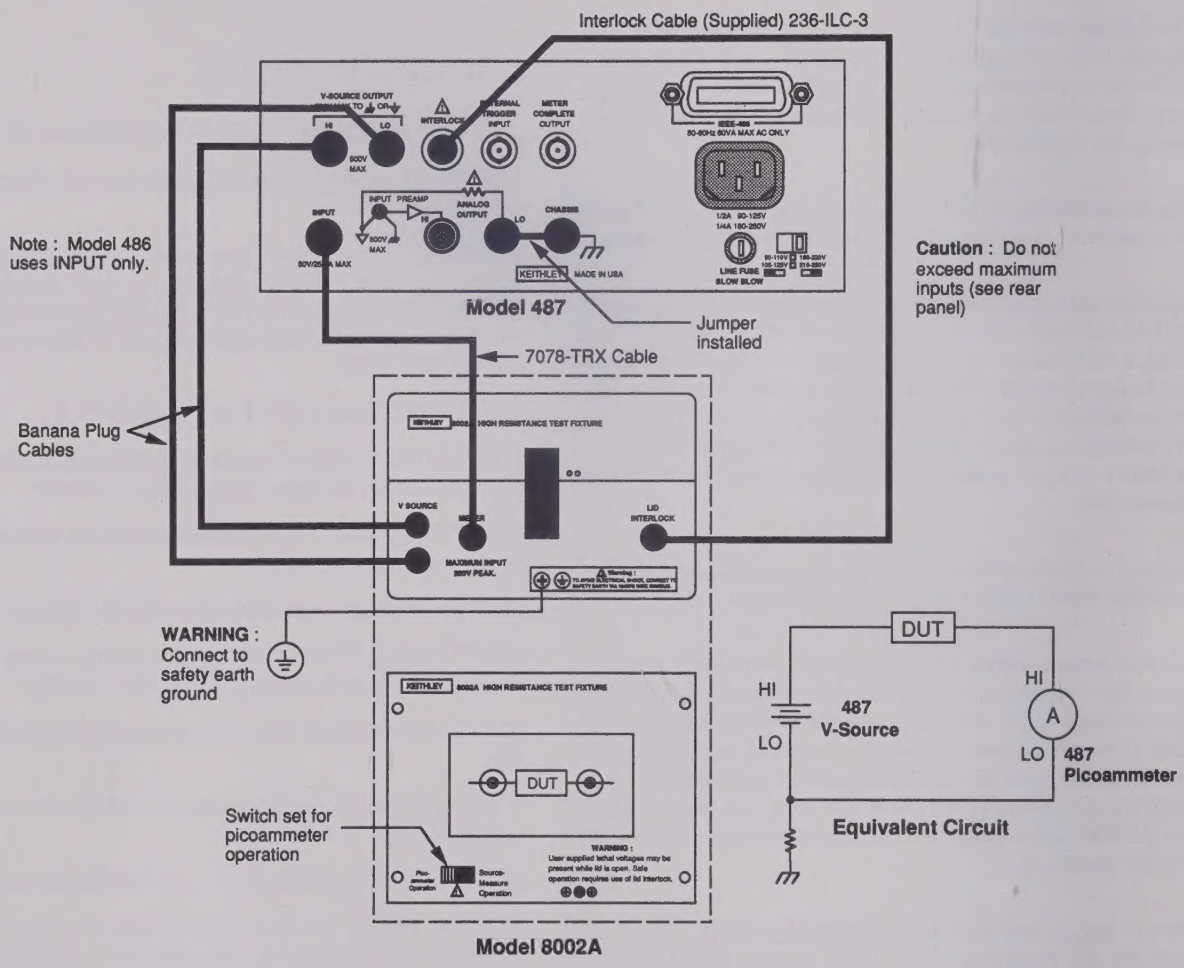
TRIGGER: Press to trigger a reading or start the data store.

PRESET: Toggles between two preset V-Source values (Model 487 only).

SHIFT OHMS (V/I): Press to select V/I Ohms.

TYPICAL CONNECTIONS

(Model 487 shown connected to Model 8002A test fixture)



SPECIFICATIONS

AMMETER

RANGE	RESOLUTION	ACCURACY (1 Year)* 18°–28°C ±(%rdg+offset)	ANALOG OUTPUT Rise Time (10%–90%) Analog Filter OFF	ON
2 nA	10 fA	0.3 + 500 fA	12 msec.	70 msec.
20 nA	100 fA	0.2 + 3 pA	4 msec.	12 msec.
200 nA	1 pA	0.15 + 20 pA	800 µsec.	4 msec.
2 µA	10 pA	0.15 + 200 pA	300 µsec.	2 msec.
20 µA	100 pA	0.1 + 2 nA	160 µsec.	370 µsec.
200 µA	1 nA	0.1 + 20 nA	160 µsec.	370 µsec.
2 mA	10 nA	0.1 + 200 nA	160 µsec.	370 µsec.

* When properly zeroed.

MAXIMUM OVERLOAD: 350V peak on nA ranges and 2µA range; 50V peak on 20µA, 200µA, and 2mA ranges. Higher voltage sources must be current limited at 3mA.

INPUT VOLTAGE BURDEN: <200µV (18°–28°C) for inputs <100µA; <2mV for 2mA input; 20µV/°C temperature coefficient.

TEMPERATURE COEFFICIENT (0°–18°C & 28°–50°C): ±(0.15 × applicable accuracy specification) per °C.

NMRR: >60dB at 50Hz (LINE 50Hz integration) or 60Hz (LINE 60Hz integration).

ANALOG OUTPUT:
Range: ±7V for 1mA load; 2V for full range input (non-inverting).
Accuracy: 2.5% on 2nA range improving to 0.5% on 2mA range; 18°–28°C.
Impedance: <100Ω, DC–2kHz.

RANGING: Automatic or manual.

AUTORANGING TIME: <200msec. to final range (analog filter OFF).

MAXIMUM READING RATES (readings/second):

INTEGRATION SETTING	RESOLUTION	CONTINUOUS INTO DATA STORE	EXTERNAL TRIGGER INTO DATA STORE	TRIGGERED VIA IEEE-488 BUS**
FAST	4½-Digit	100	180	16
LINE 60Hz	5½-Digit	40	44	14
LINE 50Hz	5½-Digit	33	38	12

** One-shot on TALK, G7 data format.

VOLTAGE SOURCE (487 only):

RANGE (maximum value)	STEP SIZE (typical)	ACCURACY (1 Yr.) 18°–28°C ±(%setting+offset)	NOISE (p-p)*** 0.1–10Hz	TEMPERATURE COEFFICIENT 0°–18°C & 28°–50°C
±505.00 V	10 mV	0.15 + 40 mV	<1.5 mV	80 ppm + 1.5 mV/°C
±50.500 V	1 mV	0.1 + 4 mV	<150 µV	50 ppm + 200 µV/°C

*** With LO terminal connected to chassis.

SELECTABLE CURRENT LIMIT: 2.5mA ±0.5mA or 25µA ±5µA.

WIDEBAND NOISE: <30mV p-p 0.1Hz to 20MHz.

TIME STABILITY: ±(0.003% + 1mV) over 24 hours at constant temperature.

OUTPUT RESISTANCE: <2.5Ω.

V/I OHMS (487 only)

Used with voltage source; resistance calculated from voltage setting and measured current. V/I OHMS accuracy equals voltage source accuracy plus ammeter accuracy. Typical accuracy better than 0.6% for readings between 1kΩ and 1TΩ.

IEEE-488 BUS IMPLEMENTATION

MULTILINE COMMANDS: DCL, SDC, GET, GTL, UNT, UNL, SPE, SPD.

UNILINE COMMANDS: IFC, REN, EOI, SRQ, ATN.

INTERFACE FUNCTIONS: SH1, AH1, T5, TE0, L4, LE0, SR1, RL1, PP0, DC1, DT1, C0, E1.

PROGRAMMABLE PARAMETERS: All parameters programmable except for IEEE-488 bus address and line integration frequency.

TRIGGER TO FIRST BYTE: <50msec. (trigger on TALK, ATN false to talker DAV true, G7 data format).

GENERAL

DATA STORE and MIN/MAX: Stores up to 512 readings and identifies minimum and maximum reading.

PROGRAMMABLE READING INTERVAL: 10msec. to 999.999 sec. in 1msec. increments.

TRIGGER: One-shot or continuous from front panel, IEEE-488 bus, and rear panel BNC.

PROGRAMMABLE TRIGGER DELAY: 1msec. to 999.999 sec. in 1msec. increments.

DISPLAY: One ten character plus one eight character alphanumeric LED displays with normal/dim/off intensity control.

MAXIMUM VOLTAGE BETWEEN VOLTAGE SOURCE AND CURRENT METER: 500V DC.

MAXIMUM VOLTAGE BETWEEN CHASSIS AND VOLTAGE SOURCE OR CURRENT METER: 500V DC.

REAR PANEL CONNECTORS:
Input Connector: 3-lug triax.
Analog Output: 5-way binding post.
External Trigger and Meter Complete: BNC connectors. IEEE-488 Connector: chassis grounded.
Voltage Source Output (487 only): 5-way binding post.
Interlock Connector (487 only): 3-pin miniature DIN.

ENVIRONMENT:
Operating: 0°–50°C, <70% RH up to 35°C; linearly derate 3% RH/°C, up to 50°C.
Storage: –25° to 60°C.

WARM-UP: 2 hours to rated accuracy.

POWER: 105–125V AC or 210–250V AC (external switch selectable), 90–110V and 180–220V AC version available. 50Hz or 60Hz, 45VA maximum.

DIMENSIONS, WEIGHT: 90mm high × 213mm wide × 397mm deep (3½ in. × 8⅜ in. × 15⅝ in.). Net weight 4.25kg (9.3 lbs.).

ACCESSORIES SUPPLIED:
Instruction Manual
Quick Reference Guide
Model 236-ILC-3 (487 only): Interlock Cable
Model 7078-ALG: 3-slot Triax to Alligator Clip Cable

Specifications subject to change without notice.

Contains general information, including features, unpacking instructions, and a brief description of available accessories.

SECTION 1
General Information

Includes an overview of the front panel and rear panel configuration and basic test procedures. Use this information to get your Model 486 or 487 up and running as quickly as possible.

SECTION 2
Getting Started

This section contains detailed information on operating the Models 486 and 487 from the front panel.

SECTION 3
Front Panel Operation

Contains information on using the Models 486 and 487 over the IEEE-488 bus.

SECTION 4
IEEE-488 Reference

Provides the procedures necessary to verify that the Models 486 and 487 are operating within stated specifications.

SECTION 5
Performance Verification

A description of operating principles for the instrument is located in this section. The various analog and digital circuits are explained.

SECTION 6
Theory of Operation

Details maintenance procedures for the Models 486 and 487, including fuse replacement, calibration and troubleshooting.

SECTION 7
Maintenance

Includes replacement parts information, schematic diagrams and component location drawings for the Model 486 and 487.

SECTION 8
Replaceable Parts

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SECTION 1
General Information

1.1 INTRODUCTION

This section contains general information about the Model 486 Picoammeter and the Model 487 Picoammeter/Voltage Source.

1.2 FEATURES

Some important Model 486/487 features include:

- Dual Displays — A 10 character alphanumeric display used for current readings and front panel messages, and a smaller 8 character alphanumeric display for front panel messages and the voltage source setting of the Model 487.
- Zero Correct — Used to cancel internal offsets.
- Relative (REL) — Used to establish baselines.
- Data Store — Can store up to 512 readings and is accessible over the bus or from the front panel.
- User Programmed Default Conditions — Establish present operating setup conditions as power-up default conditions.
- Talk-Only — From the front panel, set instrument to send readings over the bus to a listen-only device, such as a printer.
- V/I ohms resistance measurements up to 50PΩ (Model 487 only).
- Preset (Model 487) toggles between preset V-source values

1.3 WARRANTY INFORMATION

Warranty information is located on the inside front cover of this instruction manual. Should your Model 486/487 require warranty service, contact the Keithley representative or authorized repair facility in your area for further information. When returning the instrument for repair, be sure to fill out and include the service form at the back of this manual in order to provide the repair facility with the necessary information.

1.4 MANUAL ADDENDA

Any improvements or changes concerning the instrument or manual will be explained in an addendum included with the manual. Be sure to note these changes and incorporate them into the manual.

1.5 SAFETY SYMBOLS and TERMS

The following symbols and terms may be found on an instrument or used in this manual.

The symbol on an instrument indicates that the user should refer to the operating instructions located in the instruction manual.

The **WARNING** heading used in this manual explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading used in this manual explains hazards that could damage the instrument. Such damage may invalidate the warranty.

1.6 SPECIFICATIONS

Model 486/487 specifications may be found at the front of this manual.

1.7 INSPECTION

The Model 486/487 was carefully inspected, both electrically and mechanically before shipment. After unpacking all items from the shipping carton, check for any obvious signs of physical damage that may have occurred during transit. Report any damage to the shipping agent immediately. Save the original packing carton for possible future reshipment. The following items are included with every Model 486/487 order:

- Model 486 Picoammeter or Model 487 Picoammeter/ Voltage Source.
- Model 486/487 Instruction Manual.
- Model 236-ILC-3 Interlock Cable (Model 487 only)
- Model 7078-ALG Triax to Alligator-clip Cable.
- Quick Reference Guide
- Additional Accessories as ordered.

If an additional instruction manual is required, order the manual package, Keithley part number 486-901-00. The manual package includes an instruction manual and any pertinent addenda.

1.8 OPTIONAL ACCESSORIES

The following accessories are available from Keithley for use with the Model 486/487.

Model 4288-1 Single Fixed Rack Mount Kit — Mounts a single Model 486/487 in a standard 19 inch rack.

Model 4288-2 Dual Fixed Rack Mount Kit — Mounts two Model 486/487s in a standard 19 inch rack.

Model 6105 Resistivity Chamber — Use with the Model 487 to measure the volume and surface resistivity of test samples. Accommodates sheet samples 64 to 102mm (2.5 to 4 in.) in diameter and up to 6.4mm (0.25 in.) thick.

Model 6171 3-slot to 2-lug Triax Adapter — Adapts INPUT connector for 2-slot triax cables.

Model 7007 Shielded IEEE-488 Cables — Connects the Model 486/487 to the IEEE-488 bus using shielded cables to reduce electromagnetic interference (EMI). The Model 7007-1 is one meter in length and has an EMI shielded IEEE-488 connector at each end. The Model 7007-2 is identical to the Model 7007-1, but is two meters in length.

Model 7078-TRX Triaxial Cables — Low noise cables terminated with 3-slot male triaxial connectors. The Model 7078-TRX-3 is 0.9m (3 ft.) in length, the Model 7078-TRX-10 is 3m (10 ft.) in length, and the Model 7078-TRX-20 is 6m (20 ft.) in length.

Model 8002A High Resistance Test Fixture — Use with the Model 487 to make high resistance (V/I) measurements. The Model 8002 is designed to minimize leakage currents that could otherwise degrade the measurement. Connectors include one pair of 5-way binding posts, two 3-lug triaxial connectors, and a standard interlock connector for the safety interlock switch.

Model 8006 Component Test Fixture — Provides a convenient and practical way of making sensitive test measurements on a variety of standard packaged devices. Sockets are provided for resistors, diodes, 4-, 8-, 10-, and 12-lead axial (TO) packages, and DIPs up to 28 pins. Connectors include 16 3-lug triaxial, two BNC, five 5-way binding posts, and a standard interlock connector for the safety interlock switch.

SECTION 2
Getting Started

2.1 INTRODUCTION

This section contains introductory information on using the Model 486 Picoammeter and the Model 487 Picoammeter/Voltage Source. For detailed front panel and IEEE-488 bus operation, refer to Sections 3 and 4 respectively.

2.2 FRONT AND REAR PANEL CONFIGURATION

Figure 2-1 and Figure 2-2 show the respective front panels of the Models 486 and 487, while Figure 2-3 and Figure 2-4 show the respective rear panels. Each of these figures includes important information that should be reviewed before operating the instrument.

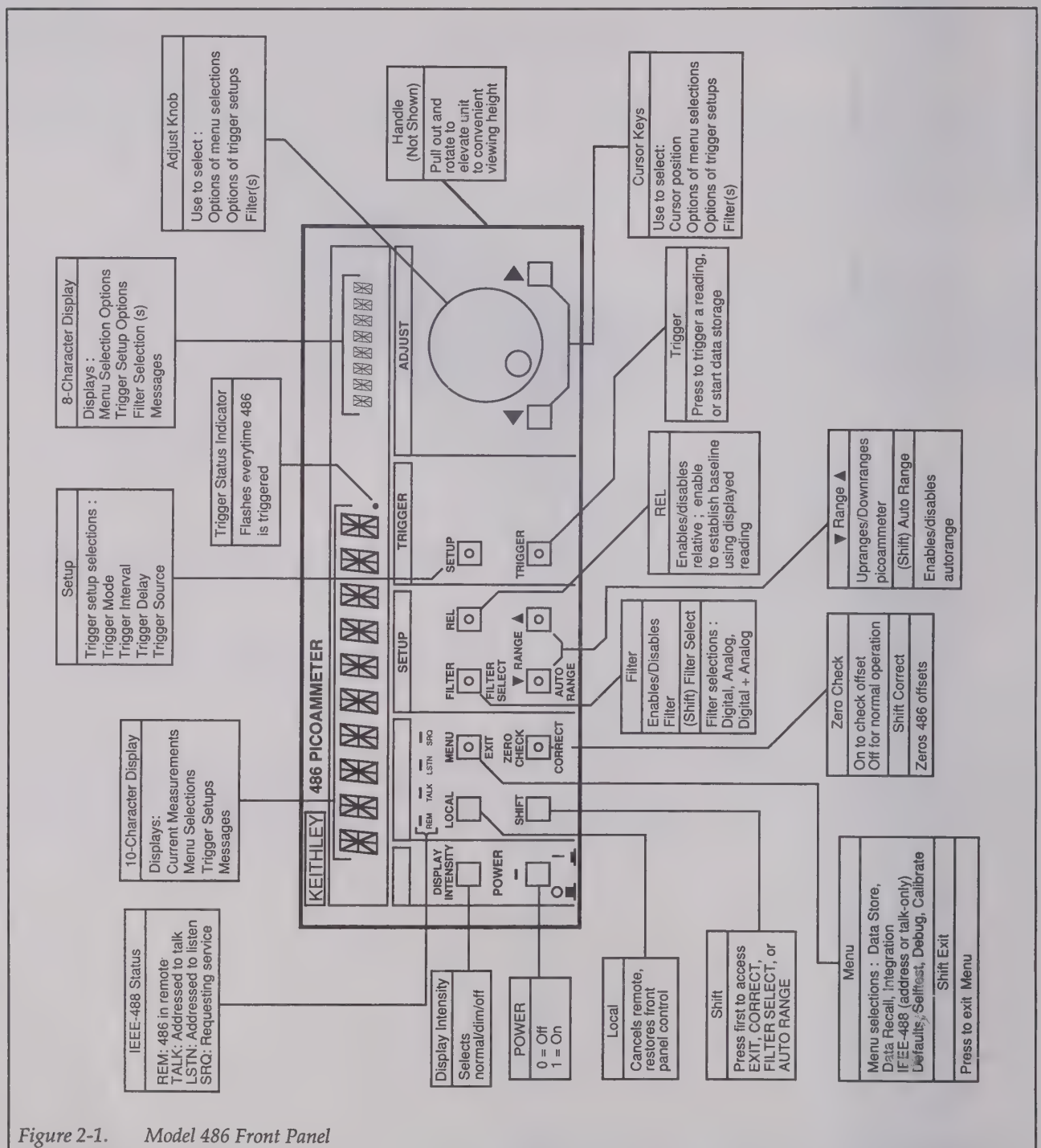


Figure 2-1. Model 486 Front Panel

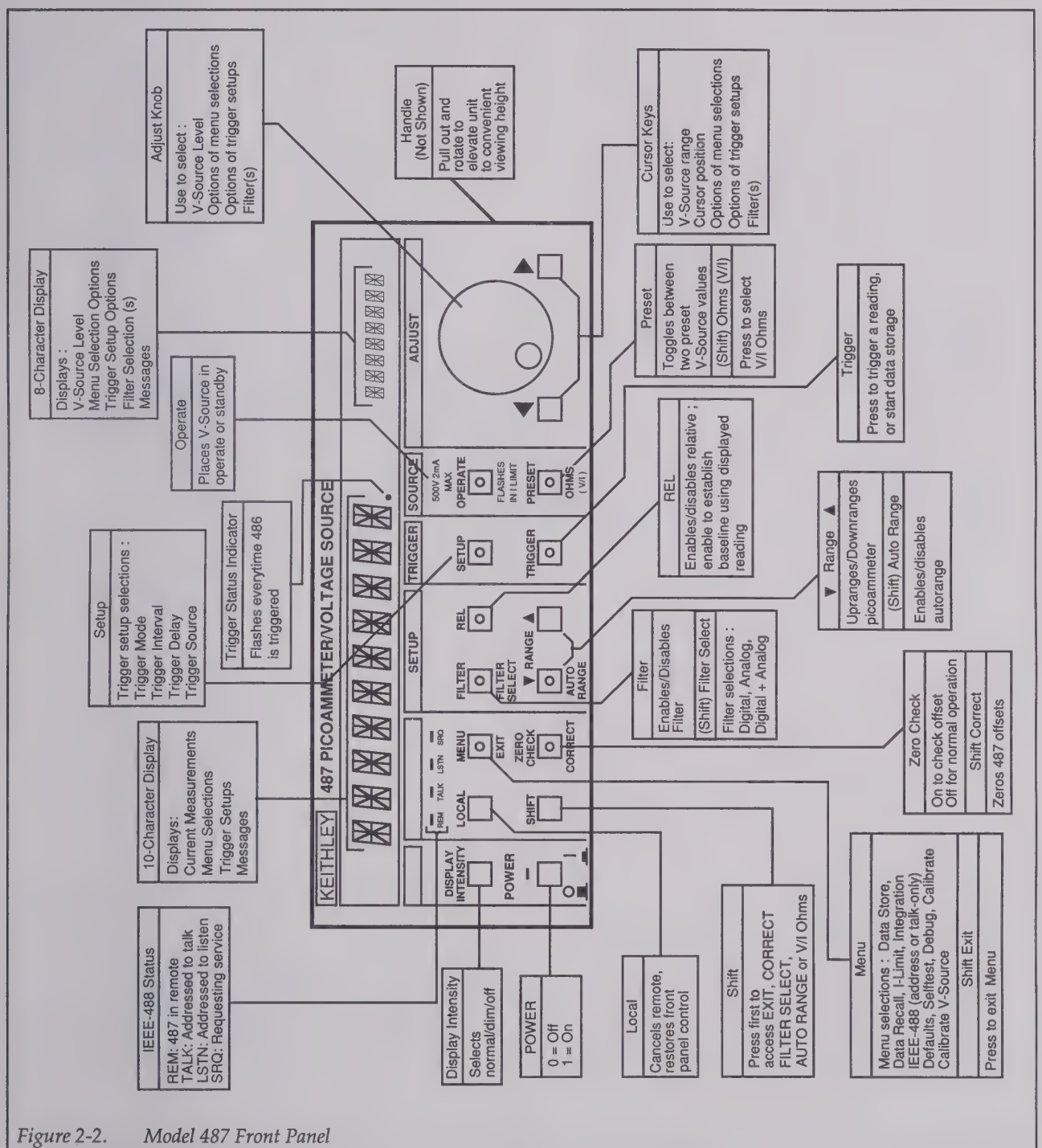


Figure 2-2. Model 487 Front Panel

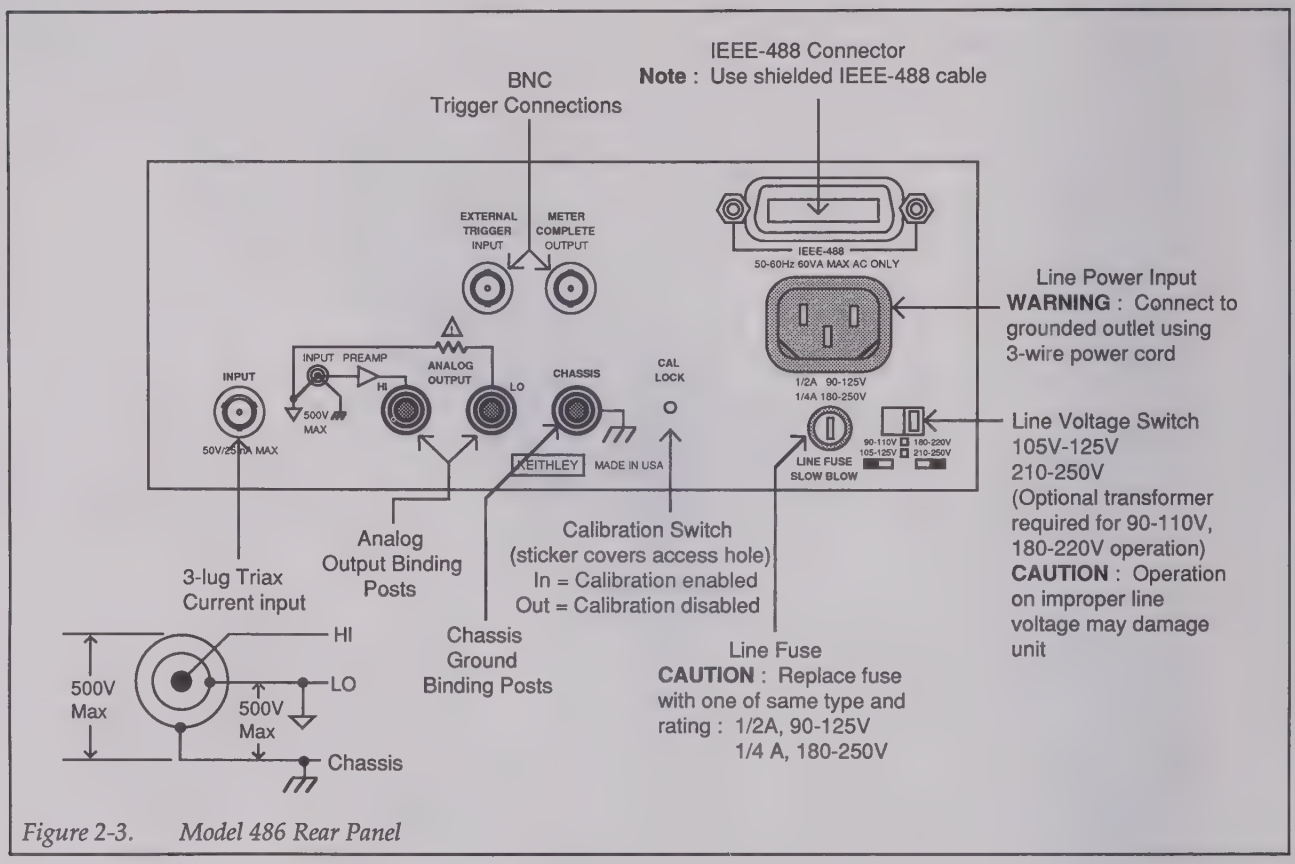


Figure 2-3. Model 486 Rear Panel

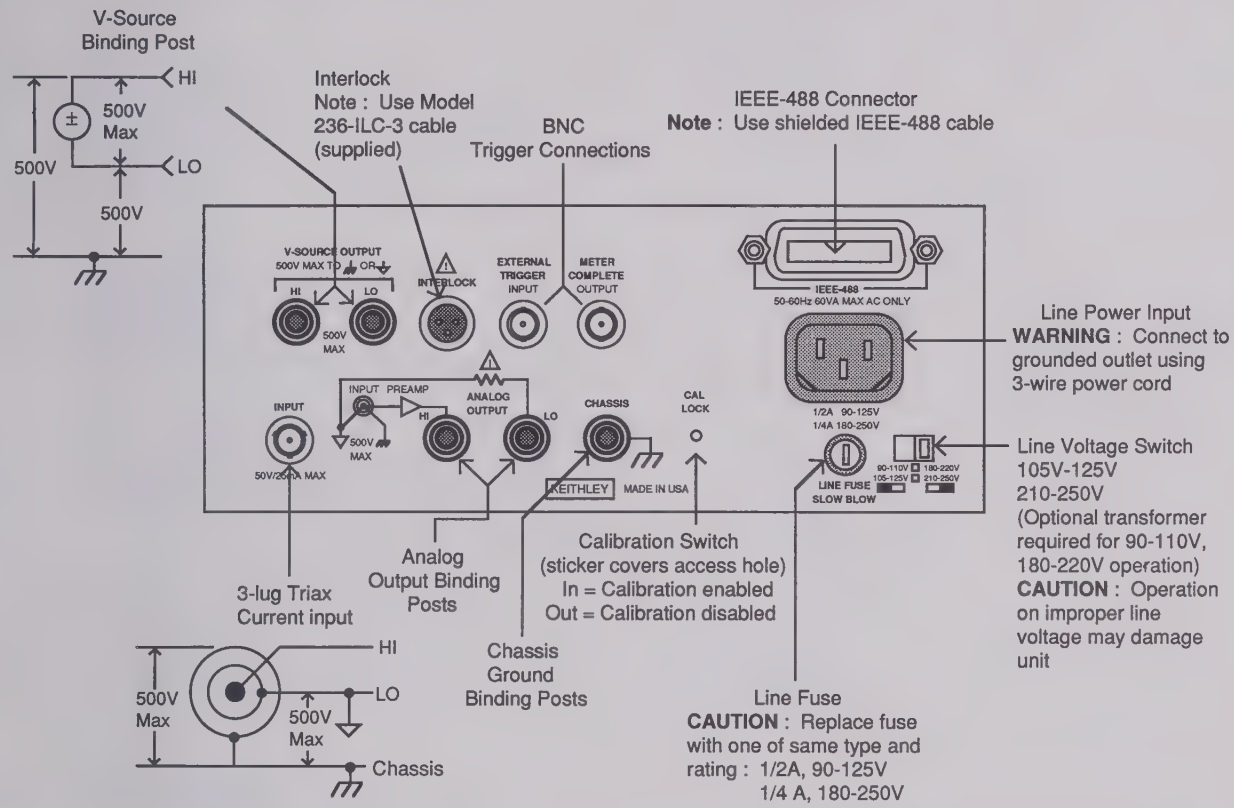


Figure 2-4. Model 487 Rear Panel

2.3 BASIC FRONT PANEL OPERATION

The following presents the basic information needed to use the Model 486/487 to make current measurements. For the Model 487, a procedure to use the voltage source in conjunction with the picoammeter is provided to demonstrate V/I Ohms resistance measurements.

Before attempting to operate the instrument, verify that the rear panel line voltage switch is in the correct position for the power line voltage in your area. Connect the instrument to an appropriate power source using the supplied line cord, then turn on the power by pressing in the front panel POWER switch.

WARNING

Use only a grounded ac outlet to avoid a possible shock hazard.

CAUTION

Operating the instrument on an incorrect line voltage may cause damage to the instrument.

NOTE

If the front panel display should appear to be inoperative, try pressing the DISPLAY INTENSITY key once or twice to restore the display to normal intensity.

2.3.1 Current Measurements

The steps below outline the basic procedure for using the Model 486/487 to make current measurements from the front panel:

1. Perform factory initialization as follows to return the instrument to factory default conditions:
   A. Press and release MENU until the following message is displayed:

      DEFAULTS OK

   B. Use the rotary knob, or the ◀ and ▶ keys to display the following message:

      DEFAULTS FACTORY

   C. Press MENU. The instrument will return to the normal measurement display state.

   Note: Performing factory initialization is a convenient method to return the instrument to typically used operating states. Using factory defaults, zero check is enabled, autorange is enabled, and filter (digital + analog) is enabled.

2. Connect the rear panel triax INPUT connector to the current source. For example, Figure 2-5 shows a Keithley Model 263 source connected to the Model 486/487.
3. On the Model 486/487, press SHIFT and then CORRECT to perform zero correction. This will cancel any internal offsets.
4. On the Model 486/487, disable zero check by pressing ZERO CHECK. The ZERO CHECK indicator will turn off.
5. If you intend to suppress an offset current from the external current source, perform the following steps:
   A. Apply the current to be suppressed to the input. That current will be measured and displayed on the Model 486/487.
   B. On the Model 486/487, press REL. The current will be suppressed as indicated by the zeroed display.
6. Apply the signal current to be measured to the input of the Model 486/487.
7. Read the current measurement on the display of the Model 486/487.
8. When the measurement is complete, enable zero check to avoid accidental overloads to the instrument. In general, zero check should be left enabled while the instrument is turned on but not in use.

2.3.2 V/I Ohms Measurements (Model 487)

NOTE
The following procedure demonstrates how to properly use the V-Source of the Model 487. Keep in mind that the V-Source can be used as an independent source for any appropriate application.

For V/I Ohms resistance measurements, the Model 487 sources a voltage to a device under test (DUT) and measures the subsequent current. The resistance value of the DUT is automatically calculated (R = V/I) and displayed in ohms.

The steps below outline the basic procedure for using the Model 487 to make V/I Ohms measurements from the front panel:

1. Perform factory initialization as follows to return the instrument to factory default conditions:
   A. Press and release MENU until the following message is displayed:

      DEFAULTS OK

   B. Use the rotary knob, or the ◀ and ▶ keys to display the following message:

      DEFAULTS FACTORY

   C. Press MENU. The instrument will return to the normal measurement display state.

   Note: Performing factory initialization is a convenient method to return the instrument to typically used operating states. Using factory defaults, zero check is enabled, autorange is enabled, filter (digital + analog) is enabled, I-limit is set to 2.5mA.

2. Select the V/I Ohms function by pressing SHIFT and then OHMS (V/I).
3. With the DUT installed in an appropriate test fixture, connect it to the V-Source and picoammeter of the Model 487. Figure 2-6 shows how to connect a DUT that is installed in the Keithley Model 8002A test fixture to the Model 487.

WARNING
To prevent contact with possible hazardous voltages, make sure the Model 487 interlock

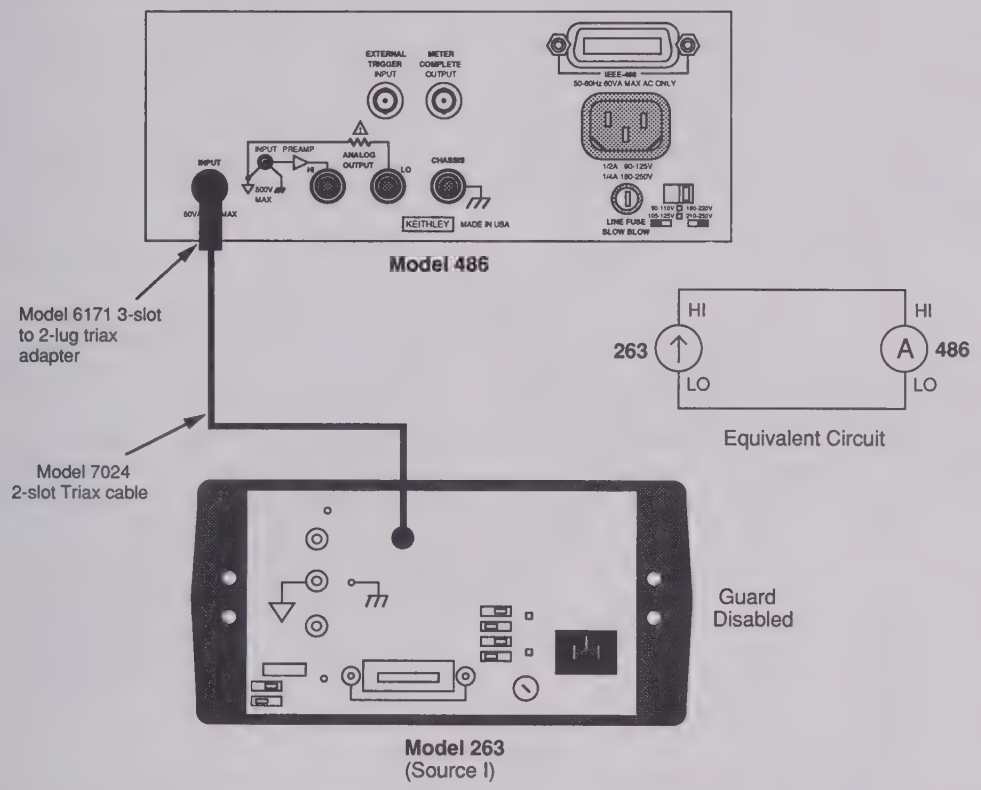


Figure 2-5. Connections to Measure Current

is properly connected to the test fixture (see Figure 2-6). With proper use of Interlock, the V-Source will not apply voltage to the test fixture when the lid of the test fixture is open.

WARNING

To provide protection from shock hazards, the test fixture chassis must be properly connected to a safety earth ground. A grounding wire (18 AWG or larger) must be attached securely to the test fixture at a screw terminal designed for safety grounding. The other end of the ground wire must then be attached to a known safety earth ground.

4. On the Model 487, press SHIFT and then CORRECT to perform zero correction. This will cancel any internal offsets.

5. Set the V-Source of the Model 487 to the desired voltage level as follows:
   A. Select the V-Source range. To select the 50V range, keep pressing and releasing the ▶ key until the 50V range is displayed (i.e. 0V on the 50V range is displayed as "00.000V"). To select the 500V range, keep pressing and releasing the ◀ key until the 500V range is displayed (i.e. 0V on the 500V range is displayed as "000.00V").
   B. Use the ◀ and ▶ keys to position the cursor (flashing digit) on the digit to be modified.
   C. Use the rotary knob to increase or decrease the voltage level from the selected digit.

   Note: As a general rule, the V-Source should be set as high as possible to optimize V/I Ohms measurement accuracy.

6. On the Model 487, press ZERO CHECK to disable zero check, and press OPERATE to apply the programmed voltage to the test fixture. The resistance of

the DUT will be measured and displayed on the Model 487.

Note: Using the setup in Figure 2-6, resistance will be displayed as a positive value. As long as both current and voltage read positive (or both read negative), then the V/I calculation will be displayed positive. Negative V/I is displayed only if the V-Source or picoammeter (but not both) have a negative read out. V/I Ohms is simply the calculation of voltage setting divided by meter reading.

7. When finished, place the V-Source in standby and enable zero check.

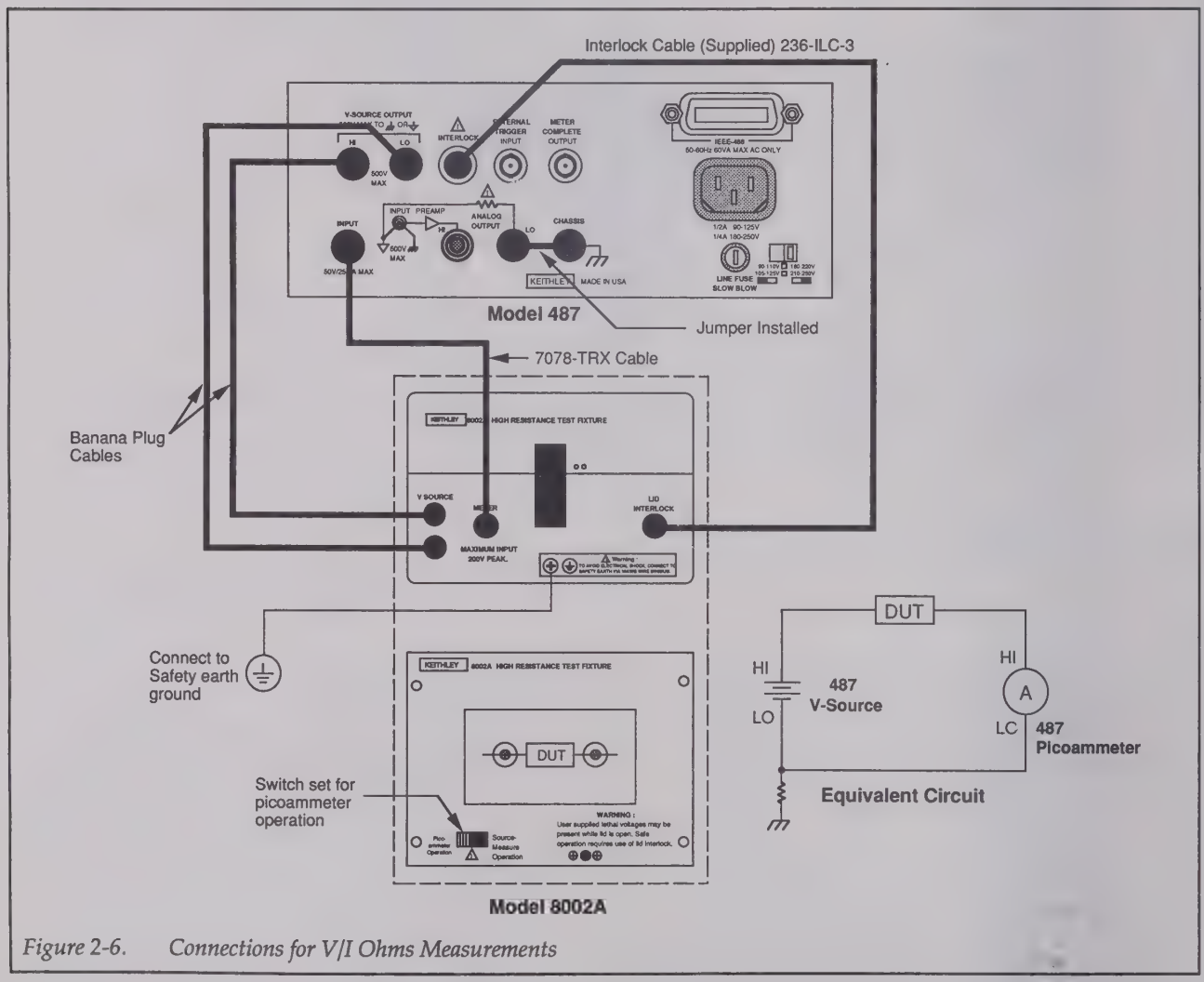


Figure 2-6. Connections for V/I Ohms Measurements

2.4 BASIC IEEE-488 OPERATION

The following information outlines the basic procedures to use the Model 486/487 over the IEEE-488 bus. An abbreviated summary of commands necessary for basic operation is shown in Table 2-1. Simple controller programs that can be used to send these commands are listed in Appendix D of this manual.

Before attempting to operate the instrument, perform the following steps:

1. With the power off, connect the Model 486/487 to the IEEE-488 bus of the controller. A shielded IEEE-488 cable such as the Keithley Model 7007 is recommended.
2. Verify that the rear panel line voltage switch is in the correct position for the power line voltage in your area. Connect the instrument to an appropriate power source using the supplied line cord, then turn on the power by pressing in the front panel POWER switch.

WARNING

Use only a grounded ac outlet to avoid a possible shock hazard.

CAUTION

Operating the instrument on an incorrect line voltage may cause damage to the instrument.

NOTE

If the front panel display should appear to be inoperative, try pressing the DISPLAY INTENSITY key once or twice to restore the display to normal intensity.

3. Verify that the programmed primary address displayed on power-up is the same as the one you intend to specify in your program statements. For example, if the instrument is currently set for an address of 22, the following message will be briefly displayed on power-up.

   IEEE-488 ADDR 22

4. If you desire to change the primary address of the instrument, you can do so as follows:
   A. Press and release MENU until the IEEE-488 address is displayed.
   B. Use the rotary knob (or the ◀ or ▶ key) to display the desired address (0-30).
   C. With the desired address displayed, press MENU to save it.
   D. Press SHIFT and then EXIT to return to normal operation.

Table 2-1. Abbreviated Command Summary

Command	Description
C0	Disable zero check
C1	Enable zero check
C2	Enable zero check and perform zero correction
F0	Disable V/I ohms (Model 487)
F1	Enable V/I ohms (Model 487)
L0	Return to factory default conditions and save (L1)
L1	Save present states as default conditions
L2	Return to saved default conditions
L3,v	Calibrate present measurement range using "v"; v = –2E–3 to +2E–3 amps
L4	Calibrate zero on present voltage source range (Model 487)
L5	Calibrate full scale on present voltage source range (Model 487)
L6	Prepare to calibrate present voltage source range (Model 487)
O0	Place Model 487 V-Source in standby
O1	Place Model 487 V-Source in operate
P0	Disable digital and analog filters
P1	Enable digital filter; disable analog filter
P2	Disable digital filter; enable analog filter
P3	Enable digital and analog filters
R0	Enable autorange
R1	Select 2nA range
R2	Select 20nA range
R3	Select 200nA range
R4	Select 2µA range
R5	Select 20µA range
R6	Select 200µA range
R7	Select 2mA range
R8	No range
R9	No range
R10	Disable autorange
Vn,r,l	Specify voltage source (Model 487) level "n" in volts, range "r" and limit "l"; n: –505.000 to +505.000 r: 0 = 50V range; 1 = 500V range l: 0 = 25µA limit; 1 = 2.5mA limit
X	Execute other device-dependent commands
Z0	Disable relative
Z1	Enable relative using present reading as baseline
Z2,v	Enable relative using "v" as baseline; v = –2E–3 to +2E–3 amps for current v = 0Ω to 5.05E16Ω for V/I ohms
Z3	Enable relative using baseline previously defined.

2.4.1 Current Measurements Over the Bus

Perform the following steps to make current measurements over the bus:

1. Boot up your computer and load your test program (again, see Appendix D for programs that can be used to send commands).

   NOTE
   If using a program from Appendix D, a reading will be sent to the computer and displayed every time you input a command string.

2. Send the following command to perform factory initialization:

   L0X

   Performing factory initialization is a convenient method to return the instrument to typically used operating states. With factory defaults, zero check is enabled, autorange is enabled, and filter (digital + analog) is enabled.

3. Connect the rear panel triax INPUT connector to the current source. For example, Figure 2-5 shows a Keithley Model 263 source connected to the Model 486.
4. To cancel internal offsets, send the following command to perform zero correction:

   C2X

5. Disable zero check by sending the following command:

   C0X

6. If you intend to suppress an offset current from the external current source, perform the following steps:
   A. Apply the current to be suppressed to the input. That current will be measured and displayed on the Model 486/487.
   B. Send the following command to perform suppression:

      Z1X

7. Set the external current source to apply the signal current to be measured to the input of the Model 486/487.
8. The current measurement is displayed on the Model 486/487. To send and display the reading on the computer CRT, the Model 486/487 must be addressed to talk.
9. When finished, enable zero check by sending the following command:

   C1X

2.4.2 V/I Ohms Measurements Over the Bus (Model 487)

For V/I ohms measurements, the Model 487 sources a voltage to a device under test (DUT) and measures the subsequent current. The resistance value of the DUT is automatically calculated (R = V/I) and displayed.

Perform the following steps to make V/I ohms measurements over the bus:

1. Boot up your computer and load your test program (again, see Appendix D for programs that can be used to send commands).

   NOTE
   If using a program from Appendix D, a reading will be sent to the computer and displayed every time you input a command string.

2. Send the following command to perform factory initialization:

   L0X

   Performing factory initialization is a convenient method to return the instrument to typically used operating states. With factory defaults, zero check is enabled, autorange is enabled, filter (digital + analog) is enabled, and I-limit is set for 2.5mA.

3. Select the V/I ohms function by sending the following command:

   F1X

4. With the DUT installed in an appropriate test fixture, connect it to the V-Source and picoammeter of the Model 487. Figure 2-6 shows how to connect a DUT

that is installed in the Keithley Model 8002A test fixture to the Model 487.

WARNING

To prevent contact with possible hazardous voltages, make sure the Model 487 interlock is properly connected to the test fixture (see Figure 2-6). With proper use of Interlock, the V-Source will not apply voltage to the test fixture when the lid of the test fixture is open.

WARNING

To provide protection from shock hazards, the test fixture chassis must be properly connected to a safety earth ground. A grounding wire (18 AWG or larger) must be attached securely to the test fixture at a screw terminal designed for safety grounding. The other end of the ground wire must then be attached to a known safety earth ground.

5. To cancel internal offsets, send the following command to perform zero correction:

   C2X

6. Use the V command to program the V-Source. For example, to set the V-Source for 10V, send the following command string:

   V10X

   Note: As a general rule, the V-Source should be set as high as possible to optimize measurement accuracy.

7. Disable zero check by sending the following command:

   COX

8. To source voltage to the DUT, place the V-Source in operate with the following command:

   O1X

9. The resistance measurement is displayed on the Model 487. To send and display the reading on the computer CRT, the Model 487 must be addressed to talk.

10. When finished, enable zero check and place the V-Source in standby by sending the following command string:

    C1O0X

SECTION 3
Front Panel Operation

3.1 INTRODUCTION

This section contains the detailed information necessary to use the instrument from the front panel. These operations (except for IEEE-488 address selection and frequency for line integration) can also be programmed over the IEEE-488 bus, as described in Section 4.

3.2 POWER-UP PROCEDURE

3.2.1 Line Voltage Setting

The instrument is designed to operate from 105-125V or 210-250V line power ranges. A special transformer may be installed (at factory) for 90-110V and 180-220V ranges. The operating voltage that the instrument is configured to operate at is indicated on the line voltage slide switch located on the rear panel (see Figure 3-1). The required switch positions for the available line voltages are summarized in Table 3-1. If the line voltage setting needs to be changed, proceed as follows:

Table 3-1. Line Voltage Selection (50-60Hz)

Line Voltage	Voltage Selection Switch Position
105–125V	115V
210–250V	230V
90–110V*	115V
180–220V*	230V

*Requires special power transformer, installed at the factory.

WARNING

Make sure the Model 486/487 is disconnected from the power line and all other equipment before proceeding.

1. Locate the line voltage switch on the rear panel (see Figure 3-1). Place the blade of a screwdriver into slot in the switch slot and slide it over to the alternate position.
2. Install a fuse consistent with the operating voltage, as described in the next paragraph.

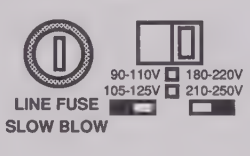


Figure 3-1. Line Voltage Switch and Line Fuse

3.2.2 Fuse Replacement

A rear panel fuse located adjacent to the line voltage switch (see Figure 3-1) protects the power line input of the instrument. If the fuse needs to be replaced (line voltage switch setting changed or suspected blown fuse), perform the following steps:

WARNING

Make sure the instrument is disconnected from the power line and other equipment before replacing the fuse.

1. With the power off, place the end of a flat-blade screwdriver into the slot in the rear panel line LINE FUSE holder. Push in gently and rotate the fuse carrier one-quarter turn counterclockwise. Release pressure on the holder and its internal spring will push the fuse and carrier out of the holder.
2. Remove the fuse and replace it with the type recommended in Table 3-2.

CAUTION

Do not use a fuse with a higher current rating than specified, or instrument damage may occur. If the instrument repeatedly blows fuses, locate and correct the cause of the trouble before replacing the fuse. See the maintenance section for troubleshooting information.

Table 3-2. Line Fuse Selection

Line Voltage	Fuse Type	Keithley Part Number
90-125V	1/2A, 250V, 3AG, Slo Blo	FU-4
180-250	1/4A, 250V, 3AG, Slo Blo	FU-17

3. Install the new fuse and the fuse carrier into the holder by reversing the above procedure.

3.2.3 Power Cord

Connect the female end of the power cord to the ac receptacle on the rear panel of the instrument. Connect the male end of the cord to a grounded ac outlet.

WARNING

The instrument is equipped with a 3-wire power cord that contains a separate ground wire and is designed to be used with grounded outlets. When proper connections are made, instrument chassis is connected to power line ground. Failure to use a grounded outlet may result in injury or death due to electric shock.

CAUTION

Be sure that the power line voltage agrees with the indicated range on rear panel line voltage switch. Failure to observe this precaution may result in instrument damage not covered by the warranty.

3.2.4 Power Up Sequence

To turn on the instrument, depress the POWER button. During the power up cycle, the unit will perform the following:

1. The instrument will perform self-tests on its memory elements. If a failure occurs, one or more of the following error messages will be displayed:

   ROM ERROR
   RAM ERROR
   NO DEFLTS
   UNCAL

   The displayed error message can be cleared by pressing any front panel key. However, a problem exists and needs to be rectified (see troubleshooting information in the Section 7). A brief explanation of any displayed error message is contained in Table 3-4.

   NOTE

   If the instrument is still under warranty and a problem develops, it should be returned to Keithley Instruments, Inc. for repair.

2. Assuming the unit successfully passes the self test, it will then briefly display the firmware revision level. For example:

   REV A00.4

   The revision level of your unit will probably be different. In any case, the revision level should be recorded in case it becomes necessary to replace the firmware in the future.

3. Next, the programmed primary address will be displayed as in the following example:

   IEEE-488 ADDR 22

   At the factory, the IEEE address of the Model 486 and 487 is set to 22. If If the address has been changed by the user, then that address value will instead be displayed.

4. The unit will then begin normal operation in accordance with the power up configuration discussed in the next paragraph.

3.2.5 Default Conditions

Default conditions can be defined as the setup conditions that the instrument will return to when it is powered up (or when a DCL or SDC command is sent over the bus). The instrument will return to either factory default conditions or user saved default conditions.

Factory Default Conditions

At the factory, the Model 486/487 is set up so that the instrument is configured to certain setup conditions on the initial power up. These factory default conditions are listed in Table 3-3 (front panel operation) and Table 4-3 (IEEE-488 bus operation). If alternate setup conditions are saved (see User Saved Default Conditions), the instrument can be returned to factory default conditions using the DEFAULTS FACTORY menu selection (see paragraph 3.8.6) or sending L0 over the IEEE-488 bus (see paragraph 4.2.10).

Table 3-3. Factory Default Conditions (Front Panel)

Control/Feature	Factory Default Condition
Display Intensity*	Normal display intensity
Zero Check*	Zero check enabled
V/I Ohms*	V/I ohms disabled
Data Store	Unarmed
Operate (487)	Voltage source in standby
Filters*	Digital and analog filter enabled
Range*	Autorange enabled
Integration*	Line cycle; 60Hz
Trigger*	Multiple, 175msec interval, 0sec delay
Preset*	0V, 50V range, disabled
Voltage Source (487)*	0V level, 50V range and 2.5mA limit
Relative*	Relative disabled

*Operating aspects of these controls/features can be saved as user saved default conditions.

User Saved Default Conditions

Unique setup conditions can be saved by using the DEFAULTS SAVE menu selection (see paragraph 3.8.6) or by sending device-dependent command L1 over the IEEE-488 bus. These user saved default conditions will prevail over the factory default conditions on power-up, or when a DCL or SDC is asserted over the bus.

3.2.6 Line Cycle Integration

When using a line cycle integration period, the line cycle setting should match the frequency of the power line to ensure maximum rejection of noise caused by electromagnetic, electrostatic or conducted pickup from power supplies, or power cards and outlets. The instrument will still operate with a mismatched setting, but measurements will be noisier.

To set the integration period for your line frequency, perform the following steps:

1. Keep pressing and releasing the MENU key until the following message appears on the large display:

   INTEGRATE

2. Use the rotary knob (or ◀ and ▶ keys) to display the desired line frequency setting on the small display as shown:

INTEGRATE	LINE50HZ	(50Hz setting)
INTEGRATE	LINE60HZ	(60Hz setting)

3. Press MENU to select the displayed integration period setting. The next menu item will then be displayed.
4. Exit from the menu by pressing SHIFT and then EXIT. The instrument will return to normal operation.

Note: The selected integration period can be saved as the default condition (see paragraph 3.8.6).

3.2.7 Warm Up Period

The instrument can be used immediately when it is first turned on. However, the unit must be allowed to warm up for two hours to achieve rated accuracy.

3.3 ERROR MESSAGES

Error messages associated with front panel operation are listed and explained in Table 3-4.

Table 3-4. Error Messages

Message	Description
NO DEFLTS	Checksum error in default condition during power-up.
UNCAL	Checksum error in calibration during power-up.
ROM ERROR	Failed ROM self-test.
RAM ERROR	Failed RAM self-test.
TRG OVERUN	Trigger overrun; instrument triggered while still processing a previous trigger.
CAL VALUE	Calibration value conflicts with the currently selected range.
CAL ERROR	Calibration value not within allowable limits.
CAL LOCK	Sent calibration command with calibration switch (CAL LOCK) disabled.
CAL ZCHK	Cannot calibrate picoammeter with zero check enabled.
INTERLOCK	Tried to put V-Source in operate while an enabled safety interlock switch is open.

3.4 DATA ENTRY; BASIC RULES

The following basic rules pertain to entering data from the front panel for MENU items, TRIGGER SETUPs, FILTER SELECTions and the voltage source (Model 487). These rules, to some extent, summarize the operation of these features. The detailed information for using these features is found later in this section.

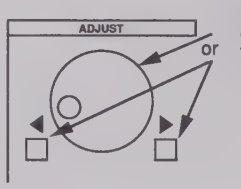
MENU, TRIGGER SETUP and FILTER SELECT

1. Menu and trigger setup items are displayed by simply pressing MENU or TRIGGER SETUP. Indicators denote the feature that is enabled.
2. Filter selections are displayed by pressing SHIFT and then FILTER SELECT in that order.
3. Options of the enabled feature are displayed by using the rotary knob or ◀ and ▶ keys (see Figure 3-2A).
4. A displayed option of a menu item is selected by pressing MENU.
5. A displayed option of a trigger setup is selected by pressing SETUP.
6. A displayed filter option is selected by pressing SHIFT and then FILTER SELECT (exits filter selection mode).

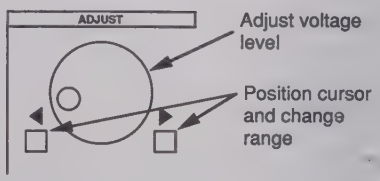
Voltage Source (Model 487)

The following basic rules to set the level of the voltage source assume that the Model 487 is in the measurement display state. Refer to Figure 3-2B for location of controls.

1. The cursor (flashing digit) for the voltage source display is enabled when the rotary knob is turned, or when a ◀ or ▶ key is pressed.
2. The position of the cursor is controlled by the ◀ and ▶ keys. With the cursor on the most significant digit, pressing ◀ will select the 500V range. With the cursor on the least significant digit, pressing ▶ will select the 50V range.
3. The rotary knob is used to adjust the voltage source level.



A. Menu, TRIGGER SETUP and FILTER SELECT

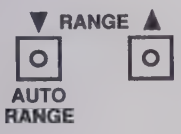


B. Voltage Source (487)

Figure 3-2. Data Entry

3.5 CURRENT MEASUREMENTS

3.5.1 Current Ranges



Range selection provides control over the sensitivity of the measurement. The available current ranges of the Model 486/487 are listed in Table 3-5. Also included in the table for each range are maximum reading and maximum input voltage overload.

Table 3-5. Current Ranges

Range	Maximum Reading (5-1/2d)	Maximum Overload*
2nA	2.19999nA	350Vdc
20nA	21.9999nA	350Vdc
200nA	219.999nA	350Vdc
2μA	2.19999μA	350Vdc
20μA	21.9999μA	50Vdc
200μA	219.999μA	50Vdc
2mA	2.19999mA	50Vdc

*Higher voltages require current to be limited to 3mA.

CAUTION

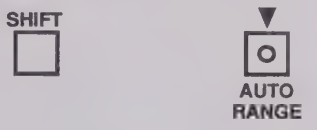
Do not exceed the maximum input voltage as specified in Table 3-5. Otherwise, damage to the Model 486/487 may result.

NOTE

After an overload occurs, it may take several minutes for the instrument to recover and display a settled reading. In general, the more severe the overload, the longer it takes to recover.

Manual range selection is accomplished with the two ranging keys. Each press and release of the RANGE ▲ key upranges the instrument to the next higher current range. Conversely, RANGE ▼ downranges the instrument to the next lower current range. Range selection can also be controlled automatically and is discussed in the next paragraph.

3.5.2 Autorange

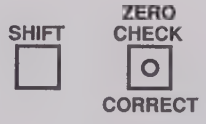


When autorange is enabled (AUTO RANGE indicator on), the instrument will automatically go to the lowest possible (most sensitive) current range to make the measurement. Autorange is enabled by pressing SHIFT and then AUTO RANGE in that order. To disable autorange, again press SHIFT and then AUTO RANGE. Autorange will also disable by manually selecting a different range using the ▼ and ▲ range keys.

CAUTION

To avoid possible damage to the instrument, do not apply more than 50Vdc to the input when autorange is enabled (unless an external series resistor to limit current to 3mA is used).

3.5.3 Zero Check and Correct



When zero check is enabled, the input amplifier is internally disconnected from the input connector of the instrument. A 100kΩ resistor shunts the input connector, and the instrument is configured to measure and display the offset of the selected range.

When zero correction is performed, the offset is measured and algebraically subtracted from every subsequent reading (including zero checked readings). This correction value is "remembered" and used until a new correction value is established by again performing zero correction. Also, an established correction value can be retained as a default condition on power up (see paragraph 3.8.6).

Zero check is enabled by pressing ZERO CHECK (ZERO CHECK indicator turns on). Pressing ZERO CHECK a second time disables the feature.

When zero correction is performed, only the present range is zero corrected. Before making measurements, it is recommended that each current range be zero corrected. The zero corrected value for each range is "remembered". The zero corrected values can be retained as default conditions on power up (see paragraph 3.8.6).

For best measurement accuracy, zero correction should be performed any time a settled zero checked display is not reading zero. Note that zero check does not have to be enabled to perform zero correction. The instrument will automatically zero check the input before performing the correction.

Perform the following steps to perform zero correction:

1. Enable zero check and allow the displayed reading to settle.
2. To perform zero correction, press SHIFT and then CORRECT in that order. The following message will be displayed while zero correction is in process:

   CORRECTING

After correction, the instrument returns to the normal measurement display state. Zero check will be on only if it was enabled in step 1.

Enabling zero check with a REL baseline established (see paragraph 3.5.5) will remove the applied signal from the input with a displayed reading as follows:

Displayed reading = input signal – relative baseline
= 0 – relative baseline
= – relative baseline

Performing zero correction will cancel (zero) only the measured offset.

Note: In the V/I ohms function, the ZERO CHECK indicator will flash if zero check is enabled. In zero check, the display will blank (– – – – – KΩ).

3.5.4 Filters

Filtering is used to stabilize noisy measurements. The Model 486/487 has two available filters; a digital filter and an analog filter. The digital filter is a function of measurement conversions. It bases the displayed (or stored) reading on the weighted average of a number of measurement conversions. The analog filter is a simple RC filter whose time constant varies with the selected range. It affects the rise time and settling time of the measurement (see Table 3-6). Rise times are defined as the time it takes the measurement to go from 10% to 90% of its final value of a step change. Settling time is the total time it takes the measurement to reach its final value (within 0.1%).

When the filter is enabled, the selected filter(s) (digital filter, analog filter or both) will be used. Filter is enabled by simply pressing FILTER (FILTER indicator will turn on). Pressing FILTER the second time will disable the filter(s).

Perform the following steps to check or change the filter selection:

Table 3-6. Analog Filter Effects

Range	Filter Disabled		Filter Enabled	
	Rise Time (10-90%)	Settling Time	Rise Time (10-90%)	Settling Time
2nA	12msec	56msec	70msec	333msec
20nA	4msec	17msec	12msec	56msec
200nA	800µsec	6msec	4msec	17msec
2µA	300µsec	2msec	2msec	6msec
20µA	160µsec	1msec	370µsec	2msec
200µA	160µsec	1msec	370µsec	2msec
2mA	160µsec	1msec	370µsec	2msec

1. Press SHIFT and then FILTER SELECT in that order. One of the following messages will be displayed to indicate the currently selected filter(s):

FILTER	DIGITAL	(Digital filter selected)
FILTER	ANALOG	(Analog filter selected)
FILTER	DIG+AN	(Both digital and analog filters selected)

2. To select a different filter, use the rotary knob, or the ◀ and ▶ keys to display the desired filter selection.
3. Enter the displayed filter selection by pressing SHIFT and then FILTER SELECT. The instrument will return to the normal measurement display state.

NOTES:

1. Typically, both filters should be used unless trying to optimize speed.
2. Factory initialization selects both analog and digital filters, and enables the filter feature.
3. The filter selection and operation (enabled/disabled) can be saved as the default condition (see paragraph 3.8.6).
4. When using the digital filter in a one-shot trigger mode, keep in mind that the first triggered conversions will not represent settled readings. A number of reading conversions are necessary to acquire a settled reading for the digital filter. For this reason, the digital filter should typically not be used when using the one-shot trigger mode.

3.5.5 Rel

The rel (relative) feature serves as a means of baseline suppression by allowing a stored offset value to be subtracted from subsequent readings. When rel is enabled, the instrument takes the currently displayed reading as a baseline value. All subsequent readings represent the difference between the applied signal level and the stored baseline.

A baseline level can be established for both current and V/I ohm measurements and is "remembered" by both functions. For example, a 1μA baseline can be established for current measurements and a 100Ω baseline can be established for V/I ohms. These levels will not be canceled by switching back and forth between functions. Once a baseline is established for a measurement function, that stored level will be the same regardless of what range the Model 486/487 is on. For example, if 1μA is established as the baseline on the 2μA range, then the baseline will also be 1μA on the 20μA, 200μA and 2mA ranges. A relative baseline level can be as large as full range. Selecting a range that cannot accommodate the baseline level will cause an overrange condition.

NOTE

The following discussion on dynamic range is based on a display resolution of 5-1/2 digits. At 4-1/2d resolution, the number of counts would be reduced by a factor of 10.

By design, the dynamic measurement range of the Model 486/487, at 5-1/2d resolution, is 439,998 counts. With rel disabled, the displayed reading range of the instrument is ±219,999 counts. With rel enabled, the Model 486/487 has the capability to display ±439,998 counts. This increased display range ensures that the dynamic measurement range of the instrument is not reduced when using a relative baseline value.

The following two examples will use the maximum allowable rel values (+219,999 counts and –219,999 counts) to show that the dynamic measurement range will not be reduced. It is important to realize that the increased display range does not increase the maximum allowable input level to the instrument. For example, on the 2mA range, the Model 486/487 will always overrange when more than ±2.19999mA is connected to the input.

Example 1 — The instrument is set to the 2mA range and a maximum –2.19999mA is established as the rel value. When –2.19999mA is connected to the input, the display will read 0.00000mA. When +2.19999mA is applied to the input, the display will read +4.39998mA. Thus, the dynamic measurement range of the Model 486 is 0mA to +4.39998mA, which is 439,998 counts.

Example 2 — The instrument is set to the 2mA range and a maximum +2.19999mA is established as the rel value. When +2.19999mA is connected to the input, the display will read 0.00000mA. When –2.19999mA is applied to the input, the display will read –4.39998mA. Thus, the dynamic measurement range of the Model 486 is 0mA to –4.39998mA, which is still 439,998 counts.

Rel is enabled by pressing the REL key (REL indicator turns on). Pressing REL a second time disables the feature.

Perform the following steps to establish a relative baseline:

1. Disable rel, if presently enabled, by pressing REL. The REL indicator will turn off.
2. Select a current range or V/I ohms range (Model 487) that is appropriate for the anticipated measurement.
3. Connect the desired baseline level to the input of the Model 486/487.
4. Press the REL key. The display will zero and the REL indicator will turn on. The previously displayed reading will be the stored level.

NOTES:

1. Enabling zero check with a rel baseline established will remove the applied signal from the input with a displayed reading as follows:

   Displayed reading = input signal – relative baseline
   = 0 – relative baseline
   = – relative baseline

2. Disabling rel cancels the rel baseline value on that selected function. A baseline established on the other function is not affected.
3. To store a new baseline, rel must first be disabled and then enabled again. the new value will be stored with the first triggered conversion.
4. Setting the range lower than the suppressed value will overrange the display.

3.5.6 Current Measurements

Input Connector

Terminal identification for the Model 486/487 input connector is shown in Figure 3-3. It is a 3-lug female triax connector that will mate to a cable terminated with a 3-slot male triax connector. The center conductor of the connector is connected to input high, the inner shell is connected to input low, and the outer shell is connected to chassis ground.

CAUTION

To prevent damage to the Model 486/487, do not exceed the maximum input levels specified in Figure 3-3.

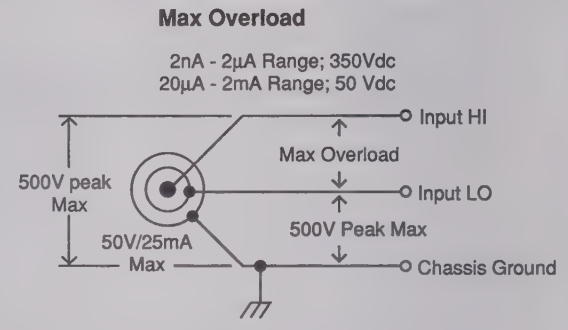


Figure 3-3. Triax Input Connector (3-Lug)

Circuit Connections

Current source connections to the Model 486/487 are shown in Figure 3-4 using the supplied triax-to-alligator cable. Note that if the current source is equipped with 3-lug triax female connector, a 3-slot triax-to-triax cable (Model 7078-TRX) could be used. A shield (connected to circuit low) should be used to minimize noise when making measurements below 1μA.

WARNING

A shock hazard, that could cause severe injury or death, exists when the input signal is at 42.4V peak or more. When this voltage level is present, a safety shield must be used as shown in Figure 3-4. Chassis ground of the Model 486/487 must be connected to the safety shield. Also, a grounding wire (18 AWG or larger) must be attached securely to the safety shield at a screw terminal designed for safety grounding. The other end of the ground wire must then be attached to a known safety earth ground.

CAUTION

To prevent damage to the instrument, adhere to the following precautions when floating the input above chassis ground:

1. Do not connect ANALOG OUTPUT LO to CHASSIS. If there is a ground link installed at the rear panel binding posts, remote it.
2. Make sure that any monitoring instrument connected to the analog output is floating.

Paragraph 3.16.8 explains the precautions for floating measurements in more detail.

Making Current Measurements

Perform the following steps to make current measurements:

1. Turn the instrument on, and allow the Model 486/487 to warm up for two hours to obtain rated accuracy.
2. Make sure the instrument is in the current function (amps reading displayed). If the V/I ohms function of the Model 487 is selected (ohms reading displayed), press SHIFT and then OHMS to place the instrument back in the current function.
3. Select a current range that is appropriate for the expected measurement or enable autorange (press SHIFT and then AUTO RANGE).
4. Enable zero check and, if the display is not zeroed, perform zero correction by pressing SHIFT and then CORRECT.

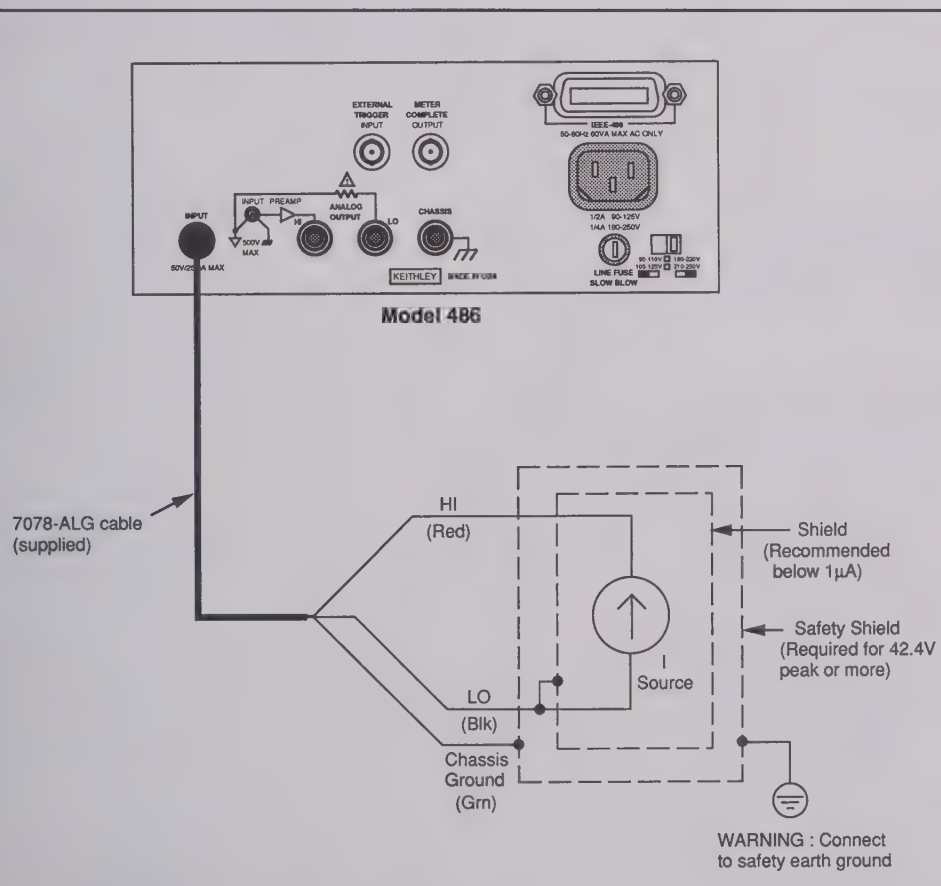


Figure 3-4. Picoammeter Connections

5. Connect the current to be measured to the input of the Model 486/487 (see Figure 3-4).
6. Disable zero check and read the measured current on the display of the Model 486/487.

Notes:

1. To prevent the possibility of oscillation, input low should typically be connected to a common low impedance, such as chassis or output low if using the V-Source of the Model 487. Only use input cables that are properly shielded and keep them as short as possible.
2. A number of other considerations that could have an affect on the integrity of current measurements are discussed in paragraph 3.16.

3.6 USING THE VOLTAGE SOURCE (Model 487)

The V-Source of the Model 487 can source up to ±505V at 2.5mA. The available voltage ranges of the V-Source are summarized in Table 3-7. This is a floating voltage source that is isolated from the chassis and signal common of the picoammeter of the Model 487. The output terminals (five-way binding posts) for the V-Source are shown in Figure 3-5. If desired, OUTPUT LO of the V-Source can be connected to chassis ground or signal common at the test fixture.

CAUTION

The voltage source may float. However, neither V-Source terminal may ever be more than 500V above chassis.

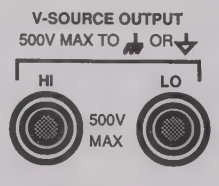


Figure 3-5. Model 487 V-Source Output Terminals

3.6.1 Test Fixture and Interlock

The voltage source of the Model 487 is designed to be used with a test fixture that incorporates a safety interlock switch, such as the Keithley Model 8002A High Resistance Test Fixture. By using the interlock feature, the Model 487 cannot source voltage when the lid of the test fixture is open or ajar.

Table 3-7. Model 487 V-Source

Range	Maximum Output	Step Size
50V	50.500V	1mV
500V	505.00V	10mV

The interlock feature is automatically enabled when the supplied interlock cable (Model 236-ILC-3) is connected to the Model 487. When using Interlock with the Model 8002A test fixture, the voltage source of the Model 487 will go into standby whenever the lid of the fixture is open or ajar. Figure 3-6 shows the interlock of the Model 487 connected (and thus, enabled) to the Model 8002A test fixture.

WARNING

Do not connect the interlock of a Model 487 to the interlock of another instrument. The interlock of the Model 487 is designed to be connected to a single-pole interlock switch of a test fixture. If connecting two or more Model 487s to a single test fixture, an isolated interlock switch for each instrument is required. Connecting multiple instrument interlocks to the same switch could cause failure of the safety interlock system.

If using a custom-built test fixture, the following requirements must be met for safe operation:

1. The metal chassis of the test fixture must be properly connected to a safety earth ground. A grounding wire (18 AWG or larger) must be attached securely to the test fixture at a screw terminal designed for safety grounding. The other end of the ground wire must then be attached to a known safety earth ground.
2. The test fixture must have a lid that closes to prevent contact with live circuitry inside. Safe operation requires that a safety interlock switch be used to interrupt all power sources when the lid of the test fixture is open or ajar. Information required to build an interlock that will be compatible with the Model 487 is provided in Figure 3-7.

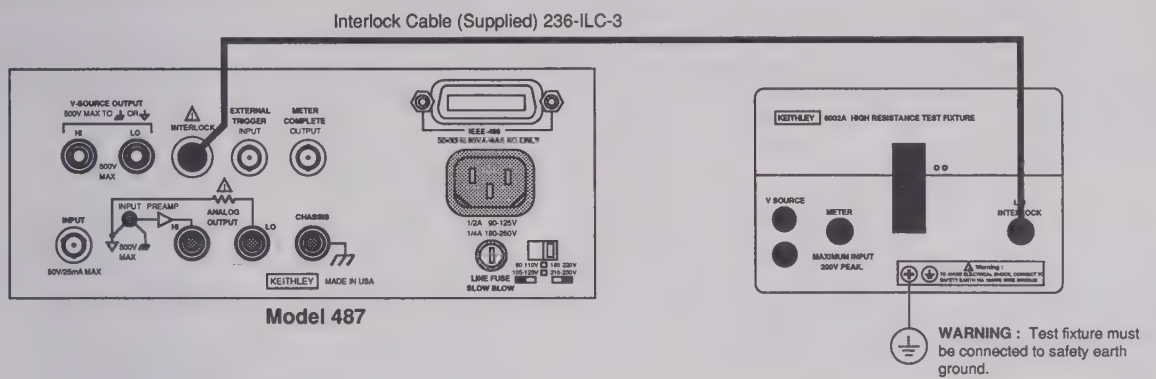


Figure 3-6. Interlock Connections

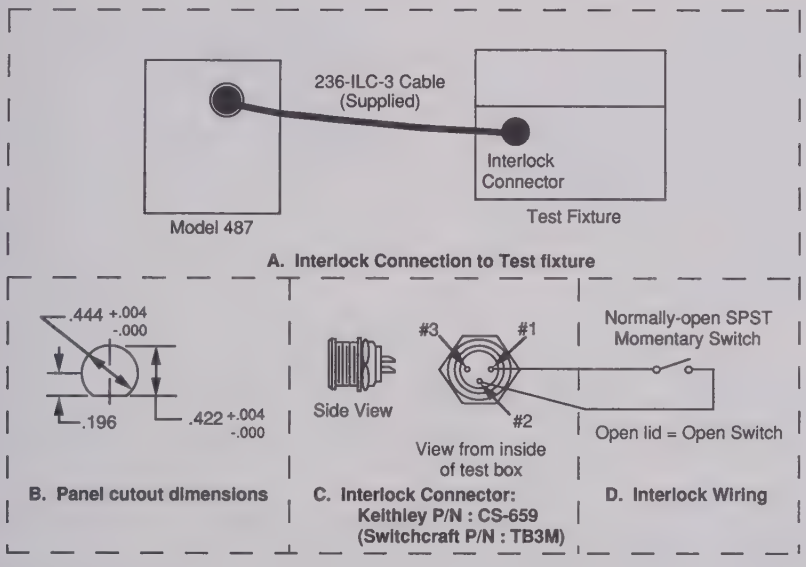


Figure 3-7. Interlock Connections

3.6.2 Adjusting V-Source Level

The rotary knob and the ◀ and ▶ keys are used to adjust the V-Source level which is displayed just above the knob (see Figure 3-8).

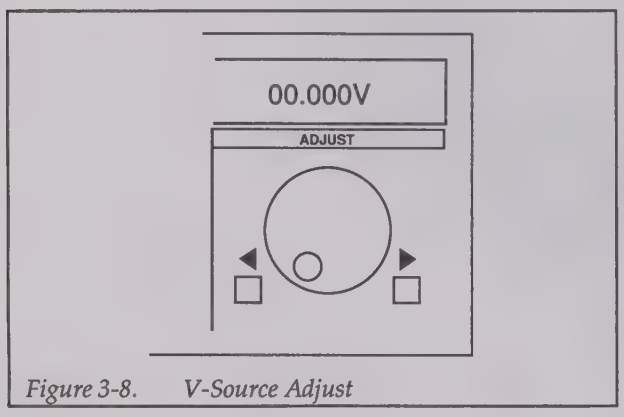


Figure 3-8. V-Source Adjust

WARNING
With the instrument in operate (OPERATE indicator on), the displayed voltage level (possibly hazardous) will be applied to the output terminals of the V-Source. The V-Source should be kept in standby until ready to safely source voltage to a load.

With the Model 487 in the normal measurement display state, perform the following steps to adjust the level of the V-Source:

1. Press ◀ or ▶ to enable the cursor.

   The cursor is indicated by the flashing digit. If an adjust action does not occur in three seconds, the cursor will disable.

2. Select the appropriate V-Source range.

   The position of the decimal point in the displayed V-Source reading denotes the selected range. For example, a reading of 00.000V is 0V on the 50V range, while a reading of 000.00V is 0V on the 500V range.

   If on the 50V range, the 500V range can be selected by pressing ◀ until the displayed range changes. Conversely, to select the 50V range, press ▶ until the range change occurs.

3. Position the cursor on the digit to be adjusted.

   The position of the cursor is controlled by the ◀ and ▶ keys. Each press of the ◀ key moves the cursor to the next more significant digit. Each press of the ▶ key, moves the cursor to the next less significant digit.

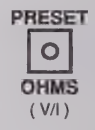
4. Adjust the voltage source level.

   The rotary knob is used to adjust the voltage source level. Turning the knob clockwise increases the voltage level at the cursor position, and conversely, turning it counter-clockwise decreases the voltage level.

   Cursor position determines how much the displayed value changes with each detent turn of the knob. For example, with the cursor on the tenths digit of the displayed value, each detent turn of the knob will increase or decrease the value by 1/10 volt (100mV).

NOTE: For best accuracy, use the 50V range to source ±50.5V or less.

3.6.3 Preset



Preset allows the V-Source to be adjusted to a predetermined level at the touch of a single key. This feature eliminates the tedious task of manually adjusting the V-Source to a frequently used level.

Perform the following steps to preset a V-Source level:

1. Enable preset by pressing PRESET. The PRESET indicator will turn on.
2. Adjust the V-Source to the desired range and level using the ◀ and ▶ keys, and rotary knob as previously explained.
3. Disable preset by again pressing PRESET. The voltage source will return to the level it was previously set to.

Whenever preset is enabled, V-Source will adjust to the value set in step 2.

NOTES:

1. A preset V-Source level can be saved as the default condition (see paragraph 3.8.6).

2. A preset V-Source value of 00.000V is the factory default condition.
3. With the V-Source in operate, the output will immediately update to whatever voltage value is displayed (unless I-limit occurs).

3.6.4 I-Limit

The V-Source has current limit (I-limit) capabilities to protect the instrument and external current sensitive circuitry from possible damage. The V-Source can be set for an I-limit of 25μA or 2.5mA.

When I-limit occurs, the OPERATE indicator will flash. This indicates that the V-Source is no longer sourcing the programmed voltage level to the load. For example, assume the V-Source is set to source 10V to a 250kΩ load with I-limit set to 25μA. Based on Ohms Law, the current through the load should be 40μA (10V/250kΩ = 40μA). However, because the I-limit is set to 25μA, the current through the load will be 25μA. The actual voltage applied to the load will really be 6.25V (250kΩ X 25μA = 6.25V) instead of the programmed 10V. If the 250kΩ load can handle 2.5mA without being damaged, then the I-limit could be increased to 2.5mA to prevent I-limit from occurring.

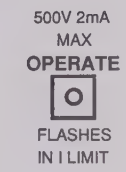
Perform the following steps to set I-limit:

1. Keep pressing and releasing MENU until the currently selected I-limit is displayed:

   ILIMIT 25μA
   or
   ILIMIT 2.5mA

2. Use the rotary knob, or ◀ and ▶ keys to display the desired I-limit value.
3. To enter the displayed I-limit, press MENU. The next menu item will be displayed.
4. To exit the menu, press SHIFT and then EXIT in that order. The instrument will return to the normal measure display state.

3.6.5 Operate



The OPERATE key toggles the output between standby and operate. In standby, the V-Source is removed from the rear panel output terminals. In operate (OPERATE indicator on) V-Source is applied to the output terminals.

A flashing OPERATE indicator denotes that the V-Source is in current limit as previously explained in paragraph 3.6.4.

CAUTION

A relay switch, in series with OUTPUT HI, is opened when the V-SOURCE is placed in standby. The transition to an open output creates a potential for noise spikes. The open output allows dielectric absorbtion to recharge capacitors to unexpected voltage levels.

3.6.6 Basic V-Source Operating Procedure

The following procedure will summarize how to use the V-Source as a separate, independent source. Using the V-Source in conjunction with the picoammeter is covered in paragraph 3.7 (V/I ohms measurements) and paragraph 3.15 (Source V Measure I). This procedure assumes that the user is familiar with the operation of the basic V-Source controls as previously explained.

Perform the following steps to use the V-Source:

1. With the V-Source in standby (OPERATE indicator off), connect the load to the V-Source output terminals as shown in Figure 3-9.
2. Use the rotary knob, ◀ and ▶ the keys to set the desired voltage range and level. Note that if previously set, a preset value can be used by enabling preset.
3. Select the appropriate I-limit (25μA or 2.5mA).
4. Press OPERATE. The OPERATE indicator will turn on to denote that the displayed voltage level is available at the output terminals.
5. To disable the V-Source, again press OPERATE. The OPERATE indicator light will turn off.

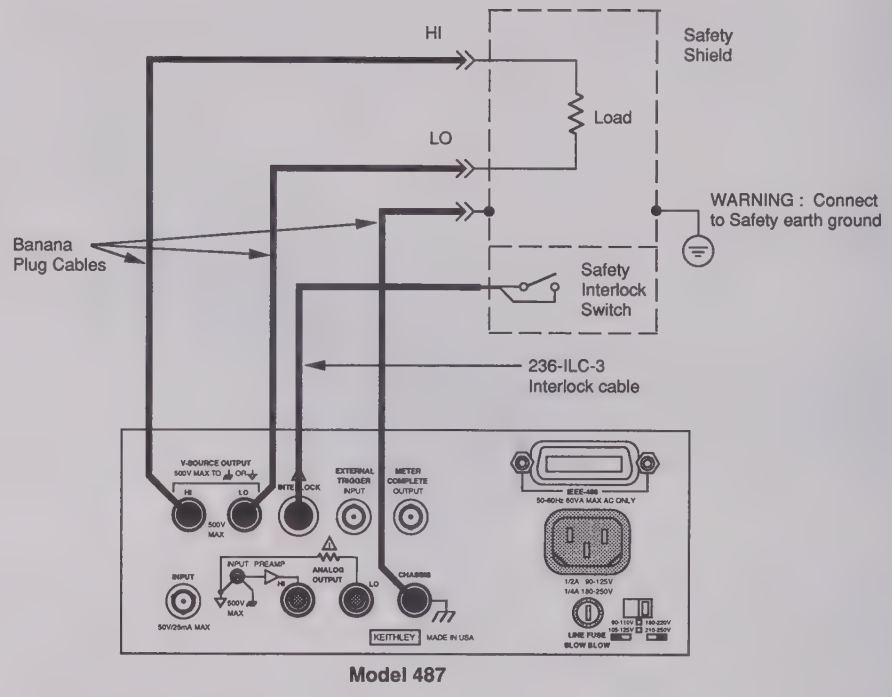


Figure 3-9. Basic V-Source Connections

3.7 V/I OHMS MEASUREMENTS (Model 487)

By using the V-Source in conjunction with its picoammeter, the Model 487 can make resistance measurements as high as $50.5 \times 10^{16}\Omega$. With V/I ohms selected, the resistance is automatically calculated from the applied voltage and measured current (R = V/I) and displayed (in ohms) on the Model 487. Actual resolution of the resistance measurement depends on the selected current range.

The V/I ohms function is enabled by pressing SHIFT and then OHMS. The display will toggle to the resistance (Ω) measurement state. To disable V/I ohms, again press SHIFT and then OHMS. The display will return to the normal amps measurement state.

Perform the following steps to make V/I ohms measurements:

1. Turn on the Model 487 and allow it to warm up for two hours to achieve rated accuracy.
2. Disable the V/I ohms function, if it is currently selected.
3. With zero check enabled and the V-Source in standby, connect the circuit shown in Figure 3-10. The Keithley Model 8002A test fixture is shown because it is ideally suited for V/I ohms measurements of 2-terminal devices.
4. Select a current range that gives the nearest full scale reading or autorange, and perform zero correction by pressing SHIFT and then CORRECT.
5. Set the V-Source to the desired voltage level.
6. Press OPERATE to turn on the source output, and disable zero check. The current measurement will be displayed.
7. Enable V/I ohms by pressing SHIFT and then OHMS. The resistance measurement will be displayed in ohms (Ω).
8. To measure from a baseline resistance, enable rel while in V/I ohms.

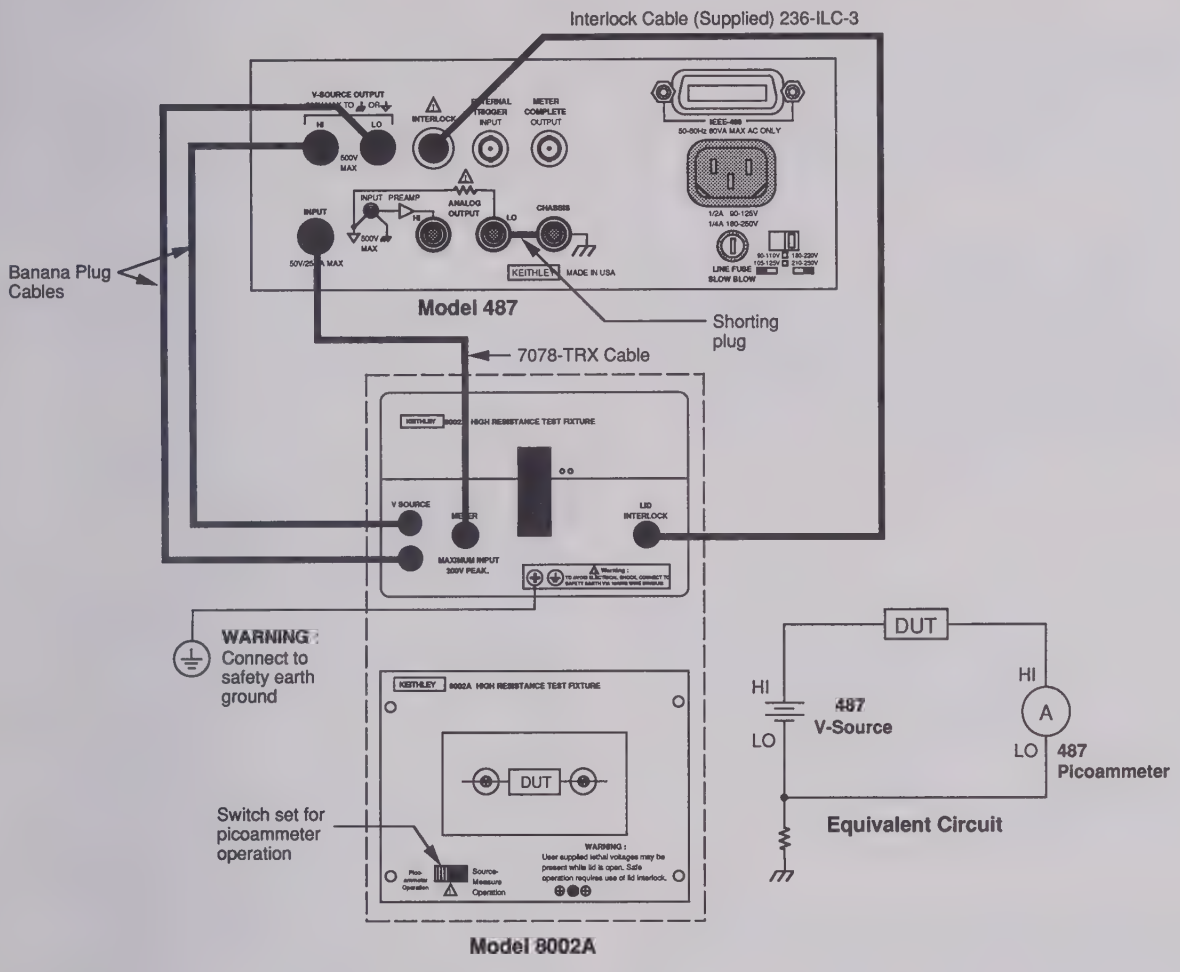


Figure 3-10. V/I Ohms Connections (Source V Measure I)

To make V/I ohms measurements, the Model 487 is configured to source voltage and measure current (Source V Measure I). The V/I feature simply performs the calculation (R = V/I) and displays the resistance reading in ohms. The results of any source V measure I test can be converted to resistance by using the V/I ohms function. Paragraph 3.15 expands on tests that source voltage and measure current, and provides some examples that are particularly applicable to the V/I ohms function.

CAUTION

To prevent damage to the instrument, adhere to the following precautions when floating the input above chassis ground:

1. Do not connect ANALOG OUTPUT LO to CHASSIS. If there is a ground link installed at the rear panel binding posts, remove it.
2. Make sure that any monitoring instrument connected to the analog output is floating.

Paragraph 3.16.8 explains the precautions for floating measurements in more detail.

NOTES:

1. Do not use zero check while in V/I ohms. Doing so will blank the display (i.e. " KΩ") and cause the ZERO CHECK indicator to flash.
2. Placing the V-Source in standby while in V/I ohms will result with zeroes being displayed (i.e. 0.00000 KΩ).
3. The minus (–) sign is not disabled in V/I ohms. Polarity changes during a test could indicate charge/discharge effects of the DUT. For example, a DUT may behave as a capacitor. At a certain voltage the capacitor will charge and display some positive resistance reading. If the V-Source is decreased, the capacitor will discharge causing current to flow in the opposite direction. A negative resistance reading will then be displayed.

Optimizing Accuracy

When using V/I ohms, the V-Source range and current range should be set up to optimize accuracy. In most cases, it is best to use the maximum voltage possible and set the current range accordingly. The instrument should be placed in the most sensitive range possible without causing an overranged condition. Doing so will optimize the measurement for resolution and accuracy. Autoranging can facilitate range selection.

V/I ohms measurements tend to be more accurate when current measured is close to full scale. Disadvantages of operating with higher voltages include power dissipation in the DUT and voltage coefficient of high impedance DUT.

Leakage Resistance

There are cases where leakage resistance could adversely affect V/I ohms measurements. For example, test fixture leakage paths may appear in parallel with the device being measured, introducing errors into the measurement. These errors can be minimized by using proper insulating material (such as Teflon®) for terminal connections in custom-built test fixtures.

NOTE

Paragraph 3.16 contains additional considerations that must be addressed when making current measurements.

3.8 MENU

The menu items are listed in Table 3-8. In general, each press of the MENU key displays a menu item in the order shown in the table. The available selections of the displayed menu item are selected and displayed with the rotary knob or the ◀ and ▶ keys. The selected option of the displayed menu item is entered by again pressing MENU. To exit the menu, press SHIFT and then EXIT.

The following information will provide the detailed steps for selecting the available options of the menu item program.

Table 3-8. MENU Items

Menu Item	Description
DATA STORE	Arm data store and set buffer size
DATA RECL	Recall data stored in buffer
ILIMIT	Set current limit; 25μA or 2.5mA (Model 487 only)
INTEGRATE	Set integration period; fast or line cycle (50 or 60Hz)
IEEE-488	Set IEEE-488 address 0-30 or select Talk-only
DEFAULTS	Save steps as power-up defaults, return to previously saved defaults, or return to factory defaults
SELFTEST	Test display and memory elements
DEBUG	Troubleshooting mode
CALIBRATE	Calibrate current range
CAL V SRC	Calibrate V-Source (Model 487 only)

3.8.1 Data Store

This menu item is used to arm the data store and select the number of readings to store in the buffer. Details for using the data store is contained in paragraph 3.11.

Data Store Selections:

NO		Do nothing
YES		Arm data store
BUFFERSIZE	000 RDGS	Wrap-around operation (circular buffer)
BUFFERSIZE	001-512 RDGS	Number of readings to store in buffer

Perform the following steps to arm the data store and set buffer size:

1. Press and release MENU until the following message is displayed:

   DATA STORE NO

   NO indicates that the data store is not armed. If you are not going to store readings, exit the menu by pressing SHIFT and then EXIT.

2. Use the rotary knob or the ◀ and ▶ keys to display the following message:

   DATA STORE YES

3. To arm the data store, press MENU. The following message will appear on the large display:

   BUFFERSIZE

   On the small display, the last programmed size value will be displayed.

4. Use the ADJUST controls to display the desired value. The ◀ and ▶ keys position the cursor on the digit to be adjusted and the rotary knob increments or decrements the value from the selected digit. For example, to store 236 readings in the buffer, adjust the value to the following display message:

   BUFFERSIZE 236 RDGS

5. With the desired buffer size value displayed, press MENU. The instrument will exit the menu and wait for a trigger to start the storage process as shown in the following example:

   –.– – – – –mA*

   The "*" indicates that the data store is armed, and the flashing TRIGGER indicator denotes that the instrument is waiting for a trigger.

NOTE: When setting buffer size, you cannot increase a selected digit that will cause the value to exceed 512. For example, if the present value is 428 with the cursor on the "4", you cannot increase it to a "5" since 528 is invalid. To increment the value 428, the cursor must be on the "2" or the "8".

3.8.2 Data Recall

This menu item is used to recall data that is stored in the buffer using the data store. Details for using the data store is contained in paragraph 3.11.

Data Recall Selections:

NO	Disable data recall
YES	Enable data recall
LOC 001-512	Stored reading at displayed buffer location
LOC MIN	Minimum reading stored in buffer
LOC MAX	Maximum reading stored in buffer

Perform the following steps to recall data stored in the data store buffer:

1. Press and release MENU until the following message is displayed:

   DATA RECL NO

   NO indicates that data recall is disabled. If you do not wish to examine stored readings, proceed to step 5.

2. Use the rotary knob or the ◀ and ▶ keys to display the following message:

   DATA RECL YES

3. Press MENU. The stored reading at memory location 001 will be displayed. For example, if the stored reading is –1.00000mA, the following will be displayed:

   –1.00000 mA LOC 001

4. The stored readings at the other memory locations (and MIN and MAX) can be examined by using the ADJUST controls. The ◀ and ▶ keys position the cursor on the digit to be adjusted and the rotary knob increments or decrements the memory location number from the selected digit. Decrementing the value from 001 displays the maximum and minimum readings.
5. To exit from data recall press MENU to display the next menu item, or press SHIFT and then EXIT to exit from the menu.

NOTES:

1. The message "NO DATA" on the small display, indicates that there are no readings stored in the buffer.
2. Turning off power, performing factory initialization, defaults recall or sending a DCL or SDC over the bus, clears the buffer (NO DATA).

3.8.3 I-Limit (Model 487)

This menu item is used to check or change the current limit setting of the V-Source of the Model 487. Details on I-limit is contained in paragraph 3.6.4.

I-Limit Selections:

2.5mA	I-limit setting of 2.5mA
25µA	I-limit setting of 25µA

Perform the following steps to check or change the I-limit:

1. Press and release MENU until the currently selected I-limit is displayed. For example, if I-limit is 25µA, the following message will be displayed:

   ILIMIT 25µA

   To retain this I-limit setting, proceed to step 3 or 4.

2. Use the rotary knob or the ◀ and ▶ keys to display the alternate I-limit.
3. Enter the displayed I-limit by pressing MENU. The next menu item will be displayed.
4. To exit from the menu, press SHIFT and then EXIT. The instrument will return to the normal measurement display state.

3.8.4 Integration

This menu selection is used to check or change the integration period for A/D conversions.

Integration Period Selections:

FAST	1.6msec integration (4-1/2 digit resolution)
LINE60HZ	Line cycle (16.67msec) integration (5-1/2 digit resolution)
LINE50HZ	Line cycle (20msec) integration (5-1/2 digit resolution)

The selectable integration periods offer a trade-off between speed, resolution and noise rejection. The fast integration period provides the fastest measurements and should be used when speed is the most important consideration. The line cycle integration periods provide slower but more stable (quieter) measurements by rejecting power line noise. To achieve the most stable measurements, select the line cycle period that matches the available line frequency.

Perform the following steps to check or change the integration period:

1. Press and release MENU until the currently selected integration period is displayed. For example, if the integration period is currently set for 60Hz line cycle, the following message will be displayed:

   INTEGRATE LINE60HZ

   To retain this integration period, proceed to step 3 or 4.
2. Use the rotary knob or the ◀ and ▶ keys to display the desired integration period.
3. Enter the displayed integration period by pressing MENU. The next menu item will be displayed.
4. To exit the menu, press SHIFT and then EXIT. The instrument will return to the normal measurement display state.

NOTE: Menu selection DEFAULT SAVE (see paragraph 3.8.6) can be used to save the selected integration period as the power-up default condition.

3.8.5 IEEE-488 Address or Talk-Only

This menu item is used to check or change the IEEE-488 address, or select talk-only.

IEEE-488 Selections:

ADDR 00-30	IEEE-488 primary address
TALKONLY	talk-only mode

At the factory, the IEEE-488 address is set to 22. However, it can be set to any valid value from 0 to 30. Section 4 contains detailed information on IEEE-488 programming. In

talk-only, the instrument will continually output data to a listening device, such as a listen-only printer. Details on using talk-only are contained in paragraph 3.13.

Perform the following steps to check or change the IEEE-488 address, or select talk-only:

1. Press and release MENU until the current IEEE-488 selection is displayed. For example, if primary address 22 is currently selected, the following message will be displayed:

   IEEE-488 ADDR 22

   To retain this selection, proceed to step 3 or 4.

2. Use the rotary knob or the ◀ and ▶ keys to display the desired address or talk-only.
3. Enter the displayed selection by pressing MENU. The next menu item will be displayed.
4. To exit the menu, press SHIFT and then EXIT. The instrument will return to the normal measurement display state.

NOTE: The instrument will power-up to the last selected IEEE-488 selection.

3.8.6 Defaults

This menu item allows you to save the present operating states as the power-up default conditions, or to return the instrument to previously saved default conditions, or to return the instrument to the factory default conditions. Factory default conditions are listed in Table 3-3. Also indicated in the table are the controls/features that can be saved as the power-up default conditions.

Default Selections:

OK	Do nothing
SAVE	Save present operating states as power-up default conditions
RECALL	Return to previously saved power-up default conditions
FACTORY	Return to factory default conditions and save as power-up default conditions.

Perform the following steps to use a default selection:

1. Press and release MENU until the following message is displayed:

   DEFAULTS OK

   If you do not wish to execute one of the other default selections, proceed to step 3 or 4.

2. Use the rotary knob or the ◀ and ▶ keys to display the desired default selection.
3. Execute the displayed default selection by pressing ENTER. If "OK" or "SAVE" is executed, the next menu item will be displayed. If "RECALL" or "FACTORY" is executed, the instrument will return to the normal measurement display state.
4. If still in the menu, you can exit from it by pressing SHIFT and then EXIT.

3.8.7 Self-Test

This menu item is used to test display segments and internal memory elements. During the display test, each segment of all the LEDs will be briefly displayed. Then, all segments of each LED will be sequentially displayed. The display test takes approximately 17 seconds to complete. After the display test, tests on its memory elements will be performed.

Self-Test Selections:

NO	Do not perform self-test
YES	Perform self-test

Perform the following steps to perform the self-test:

1. Press and release MENU until the following message is displayed:

   SELFTEST NO

   If you do not wish to run the self-test, proceed to step 5.
2. Use the rotary knob or the ◀ and ▶ keys to display the following message:

   SELFTEST YES

3. To run the test press MENU. After the display test is completed, tests on its memory elements will be performed while the following message is displayed:

   SELFTEST

4. Tests on its memory elements takes approximately five seconds. If the tests pass, the next menu item will be displayed. In the event of a failure, one of the following messages will displayed.

   ROM ERROR
   RAM ERROR

   The error message can be canceled by pressing any front panel key. However, a problem exists and must be resolved. Refer to the troubleshooting information in Section 7.
5. To exit from the menu, press SHIFT and then EXIT. The instrument will return to the normal measurement display state.

3.8.8 Debug

The debug menu item locks the A/D converter in one of three multiplexer state to allow signal tracing through the instrument during troubleshooting. Refer to paragraph 7.7 for details on using this feature.

If you have inadvertently selected debug, press MENU to display the next menu item, or press SHIFT and then EXIT to exit the menu.

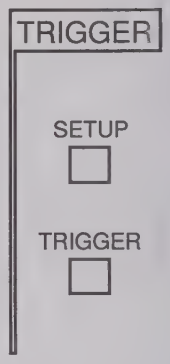
3.8.9 Calibrate

The calibrate program is used to calibrate the current ranges of the Models 486 and 487. Refer to paragraph 7.3 to calibrate the instrument.

3.8.10 Cal V SRC (Model 487)

This program is used to calibrate the V-Source of the Model 487. Refer to paragraph 7.3 to calibrate the V-Source.

3.9 FRONT PANEL TRIGGERING



The following paragraphs discuss front panel triggering, trigger mode selection, trigger interval, trigger delay and trigger source.

3.9.1 Trigger Mode

The Model 486/487 may be operated in two basic trigger modes; one-shot and multiple. In the one-shot mode, a separate trigger is required to initiate each reading. For the multiple mode, however, only a single trigger is required, with conversion rate determined by the programmed trigger interval. The multiple trigger mode is the factory default, however, the one-shot mode can be saved (see paragraph 3.8.6) as the power-up default.

To check or change the selected trigger mode, proceed as follows:

1. Press SETUP to enable trigger setup (SETUP indicator turns on). The currently selected trigger mode will be displayed. For the multiple mode, the following will be displayed:

   TRIG MODE MULTIPLE

   For the one-shot mode, the following will be displayed:

   TRIG MODE ONE-SHOT

2. To toggle the displayed trigger mode use the rotary knob or the ◀ and ▶ keys.
3. Select the displayed trigger mode by pressing SETUP to display the next trigger setup selection (trigger interval), or by pressing SHIFT and then SETUP to exit trigger setup.

3.9.2 Trigger Interval

The trigger interval determines the time period between individual readings when the instrument is in the multiple trigger mode. Interval also affects the storage rate of the data store.

The trigger interval can be set from 10msec to 999.999sec. A trigger interval of 175msec is the factory default condition. However, any valid trigger interval can be saved (see paragraph 3.8.6) as the power-up default.

Trigger interval speeds from 10msec to 49msec can only be achieved using the data store. Otherwise, an interval of 50msec or the programmed interval (whichever is greater) will be used.

NOTE
Trigger interval cannot be set in the one-shot trigger mode.

Perform the following steps to check or change the selected trigger interval:

1. Press and release SETUP until the trigger interval is displayed. For example, if the trigger interval is set for 175msec (factory default), the following will be displayed:

   TRIG INTVL 000.175

   To retain the displayed trigger interval, proceed to step 3.

2. Use the ◀ and ▶ keys, and the rotary knob to display the desired value. The ◀ and ▶ keys position the cursor on the digit to be modified, and the rotary knob increments/decrements the value from the selected digit.
3. Select the displayed trigger interval by pressing SETUP to display the next trigger setup selection (trigger delay), or by pressing SHIFT and then SETUP to exit trigger setup.

3.9.3 Trigger Delay

Trigger delay is the time from the trigger point until the unit takes a reading. In the multiple trigger mode, the delay period affects only the first conversion; however, in the one-shot trigger mode, the delay period affects every conversion, with the instrument waiting the programmed delay time after each trigger before taking a reading. For example, if you program a 300msec trigger delay, the unit will wait 300msec after each trigger before taking a reading.

The Model 486/487 can be programmed for a delay interval from 0sec to 999.999sec in 1msec increments. A trigger delay of 0sec is the factory default; however, any valid trigger interval can be saved (see paragraph 3.8.6) as the power-up default.

NOTE
If a trigger occurs during the trigger delay period, the trigger overrun (TRG OVERUN) error message will be displayed. The trigger that caused the error will be ignored.

Perform the following steps to check or change the trigger delay period:

1. Press and release SETUP until the trigger delay is displayed. For example, if the trigger delay is set for 0sec (factory default), the following will be displayed:

   TRIG DELAY 000.000

   To retain the displayed trigger delay, proceed to step 3.

2. Use the ◀ and ▶ keys, and the rotary knob to display the desired value. The ◀ and ▶ keys position the cursor on the digit to be modified, and the rotary knob increments/decrements the value from the selected digit.
3. Select the displayed trigger delay by pressing SETUP to display the next trigger setup selection (trigger source), or by pressing SHIFT and then SETUP to exit trigger setup.

3.9.4 Trigger Sources

For front panel operation, there are three trigger sources available; front panel TRIGGER key, the EXTERNAL TRIGGER INPUT jack, and the OPERATE key for the V-Source of the Model 487.

With the external trigger source selected, a trigger pulse applied to the rear panel EXTERNAL TRIGGER INPUT jack will trigger the instrument (see paragraph 3.10.1 for

details). With the operate trigger source selected, a trigger will occur when the V-Source of the Model 487 is placed in operate. The front panel TRIGGER key is always enabled, regardless of the selected trigger source; however, this key is locked out when the instrument is in remote.

Additional trigger sources include IEEE-488 X, GET, and talk commands, as discussed in Section 4.

The external trigger source is the factory default; however, any of the other trigger sources can be saved (see paragraph 3.8.6) as the power-up default condition.

Perform the following steps to check or change the trigger source:

1. Press and release SETUP until the currently selected trigger source is displayed. If external trigger source is selected, the following will be displayed:

   TRIG SRC EXTERNAL

   The other available trigger source selections:

   TRIG SRC OPERATE
   TRIG SRC BUS X
   TRIG SRC GET
   TRIG SRC TALK

   To retain the displayed trigger delay, proceed to step 3.

2. Use the ◀ and ▶ keys, or the rotary knob to display the desired trigger source.
3. Select the displayed trigger source selection by pressing SETUP. The instrument will return to the normal measurement display state.

3.9.5 Trigger Examples

Example 1:

Multiple trigger mode with a three second interval between readings:

1. Press SETUP (SETUP indicator turns on) and use the rotary knob (if necessary) to display the multiple trigger mode as follows:

   TRIG MODE MULTIPLE

2. Press SETUP and use the ◀ and ▶ keys, and rotary knob to set a trigger interval of three seconds as follows:

   TRIG INTVL 003.000

3. Press SHIFT and then SETUP. The instrument will return to the normal measurement display state. The display will update with a new reading every three seconds as indicated by the trigger status LED (flashing decimal point) that follows the reading.

Example 2:

One-shot trigger mode with a one second trigger delay:

1. Press SETUP (SETUP indicator turns on) and use the rotary knob (if necessary) to display the one-shot trigger mode as follows:

   TRIG MODE ONE-SHOT

2. Press SETUP and use the ◀ and ▶ keys, and rotary knob to set a trigger delay of one second as follows:

   TRIG DELAY 001.000

3. Press SHIFT and then SETUP. The instrument will return to the normal measurement display state.
4. To initiate a single reading, press TRIGGER. Note that the display updates after a delay of approximately one second.
5. Quickly press TRIGGER twice. The second press of TRIGGER causes a trigger overrun error. The message "TRG OVERUN" is displayed. The invalid trigger, which occurred during the delay period, is ignored.

3.10 EXTERNAL TRIGGERING

The Model 486/487 has two external BNC connectors on the rear panel associated with instrument triggering (see Figure 3-11). The EXTERNAL TRIGGER INPUT connector allows the instrument to be triggered by other devices, while the METER COMPLETE OUTPUT connector allows the instrument to trigger other devices.

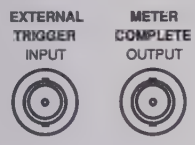


Figure 3-11. Trigger Connectors

3.10.1 External Trigger

The external trigger input requires a falling edge pulse at TTL logic levels, as shown in Figure 3-12. Connections to the rear panel EXTERNAL TRIGGER INPUT jack should be made with a standard BNC connector. If the instrument is in the external trigger source mode, it will be triggered to take readings while in either a multiple or one-shot trigger mode when the negative-going edge of the external trigger pulse occurs.

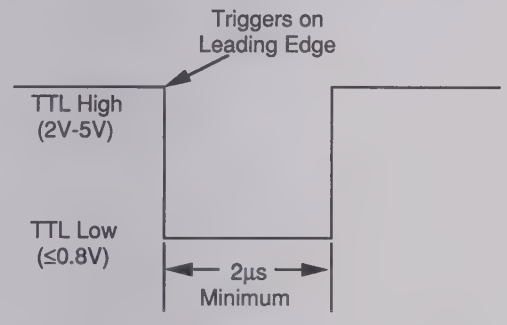


Figure 3-12. External Trigger Pulse Specifications

To use the external trigger, proceed as follows:

1. Connect the external trigger source to the rear panel BNC EXTERNAL TRIGGER INPUT connector. The outer shell (shield) of the connector to digital common.
2. Place the instrument in "one-shot on external trigger" or "multiple on external trigger" as explained in paragraph 3.9.
3. To trigger the instrument, apply a pulse to the external trigger input. The instrument will process a single reading each time the pulse is applied (one-shot), or start multiple readings.

NOTE
Triggering the unit while it is processing a reading from a previous trigger will cause a trigger overrun (TRG OVERUN).

3.10.2 Meter Complete

The Model 486/487 has an available output pulse that can be used to trigger other instrumentation. A single TTL-compatible negative-going pulse (see Figure 3-13) will appear at the METER COMPLETE OUTPUT jack each time the instrument completes a reading. To use meter complete output, proceed as follows:

1. Connect the Model 486/487 to the instrument to be triggered with a suitable shielded cable. Use a standard BNC connector to make the connection to the Model 486/487.
2. Configure the Model 486/487 to make the desired measurements.
3. In the multiple trigger mode, the instrument will output pulses at the conversion rate; each pulse will occur after the Model 486/487 has completed a conversion.
4. In the one-shot trigger mode, the Model 486/487 will output a pulse once each time it completes a reading after being triggered.

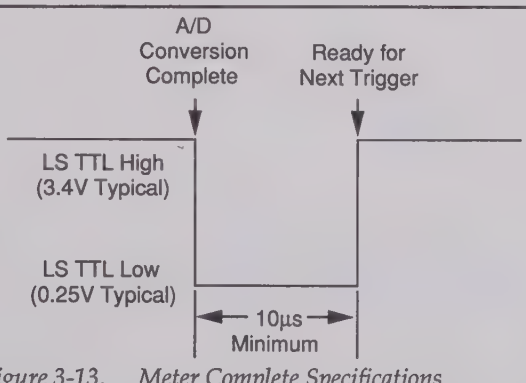


Figure 3-13. Meter Complete Specifications

3.11 DATA STORE

The data store can store up to 512 readings for later recall. Data can be stored at specific intervals of between 10msec and 999.999sec with 1msec increments. In addition, one-shot external or front panel triggering can be used to store data at arbitrary points in time.

The following paragraphs describe front panel operating procedures for storing and recalling data.

3.11.1 Storing Data at Programmed Intervals

Use the following procedure for storing data at defined intervals:

1. Select function (amps or V/I ohms) and range to be used to make measurements. Autorange may be used.
2. Set the trigger mode, interval and delay as follows:
   A. Press SETUP and verify that the multiple trigger mode is selected as follows:

      TRIG MODE MULTIPLE

      If necessary, use the rotary knob or the ◀ and ▶ keys to display the multiple trigger mode.
   B. Press SETUP and use the rotary knob or the ◀ and ▶ keys to display the desired trigger (storage) interval. For example, the following message denotes a trigger interval of 1/2 second:

      TRIG INTVL 000.500

   C. Press SETUP and use the rotary knob or the ◀ or ▶ keys to display the desired trigger delay. If you do not wish to delay the initial trigger that starts the storage process, set trigger delay to 0sec as shown:

      TRIG DELAY 000.000

   D. Exit trigger setup by pressing SHIFT and then SETUP.
3. Arm the data store and set the buffer size as follows:

   NOTE
   Details on arming the data store and entering buffer size parameters are contained in paragraph 3.8.1.

   A. Press and release MENU until the data store is selected, and use the rotary knob or the ◀ and ▶ keys to display the following message:

      DATA STORE YES

   B. Press MENU. The currently defined buffer size will be displayed. For example, if the buffer size is currently set for 100 readings, the following message will be displayed:

      BUFFERSIZ 100 RDGS

      Note: The size value determines how many readings will be stored (up to 512) before the storage cycle stops. However, a buffer size of 000 indicates that the storage cycle will continue even after all 512 readings are stored. After the 512th reading is stored, readings will be stored beginning at the first memory location, overwriting the previously stored data.

   C. Use the rotary knob or the ◀ and ▶ keys to display the desired buffer size value.
   D. Enter the data store parameters by pressing MENU. The instrument will exit the menu and will wait for a trigger to start the storage process as shown in the following example:

      –.– – – – – mA*

      The "*" indicates that the data store is armed and is waiting for a trigger as denoted by the flashing TRIGGER indicator.
4. Press TRIGGER to initiate storage. The instrument will begin storing data at the programmed interval. While storage is active, you can begin to examine stored readings by entering the data recall mode (see paragraph 3.11.3).
5. After all readings have been stored, the displayed "*" will turn off to indicate that the storage process has been completed (except for continuous wrap-around storage).

NOTES:

1. The data store can be disarmed, even after the storage process has started, by pressing ZERO CHECK, FILTER, REL, RANGE, PRESET (Model 487) or turning the rotary knob on the Model 487. The displayed "*" turns off when the data store is disarmed.
2. Arming the data store clears the buffer of previously stored readings.
3. With the operate trigger source selected (see paragraph 3.9.4), placing the V-Source of the Model 487 in operate will trigger the start of the storage process.
4. The front panel TRIGGER key can be used to start the storage process with any trigger source selected (see paragraph 3.9.4).

3.11.2 Triggering One-shot Readings into Data Store

Reading storage can be controlled by trigger pulses applied to the rear panel EXTERNAL TRIGGER INPUT (paragraph 3.10), by using the front panel TRIGGER key, or by placing the V-Source of the Model 487 in operate. In a one-shot trigger mode, each trigger stimulus will process and store a single reading.

For one-shot operation, the data store is configured the same as for multiple trigger operation as explained in the

previous paragraph. Only the trigger setup is different. The trigger mode is set for one-shot (TRIG MODE ONE-SHOT), and the trigger source is set for external (TRG SCR EXTERNAL) or operate (TRG SRC OPERATE).

In the one-shot mode, each press of the TRIGGER key will cause a single reading to be processed and stored in the buffer. The front panel TRIGGER key is active regardless of the trigger source selection. With the external trigger source selected (TRIG SRC EXTERNAL), each trigger pulse applied to the unit (see paragraph 3.9.4) will process and store a single reading. With the operate trigger source selected (TRIG SRC OPERATE), a single reading will be processed and stored each time the Model 487 V-Source is placed in operate.

NOTES:

1. Trigger interval cannot be set when in the one-shot trigger mode.
2. Trigger delay can be set in the one-shot trigger mode. Each time the trigger stimulus occurs, the reading and storage process will not occur until the delay has expired. Any triggers that occur during the delay period will result in a trigger overrun error (TRG OVERU*). The invalid trigger(s) will be ignored.

3.11.3 Recalling Data

Data can be recalled either during storage or after storage is complete by using the following procedure:

1. Press and release MENU until data recall is selected, and use the rotary knob or the <and> keys to display the following message:

   DATA RECL YES

2. Press MENU. The reading stored in the first memory location will be displayed. For example, if a 1mA reading is stored in location 001, the following message will be displayed:

   1.00000 mA LOC 001

3. For sequential access, use the rotary knob. Turning the knob counter-clockwise will display the maximum (LOC MAX) and minimum readings stored in the buffer. Turning the rotary knob clockwise will increment buffer locations until the last buffer location is reached.
4. To access a reading at a particular memory location, use the ◀ and ▶ keys to position the cursor on the desired digit and use the rotary knob to adjust the location value from the selected digit.
5. To exit data recall, press SHIFT and then EXIT.

NOTES:

1. If the data store has no valid data to display, the following message will appear in the small display upon entry into data recall:

   NO DATA

2. The instrument will continue to store data while in data recall until the data store buffer is full (unless in wrap-around operation).

3.12 ANALOG OUTPUT

The Model 486/487 has a non-inverting 2V analog output. ANALOG OUTPUT connections are shown in Figure 3-14. For a 200,000 count input, the analog output will be 2V. Typical examples are shown in Table 3-9.

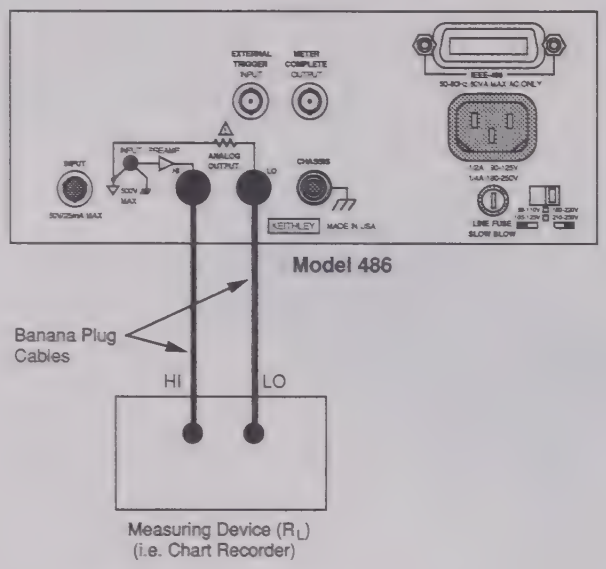
The output resistance of the analog output is 100Ω. To minimize the effects of loading, the input impedance of the device connected to ANALOG OUTPUT should be as high as possible. For example, for a device with an input impedance of 10kΩ, the error due to loading will be approximately 1%. Rel has no effect on the analog output. A 1mA input (2mA range) will result in a 1V analog output whether Rel is enabled or not.

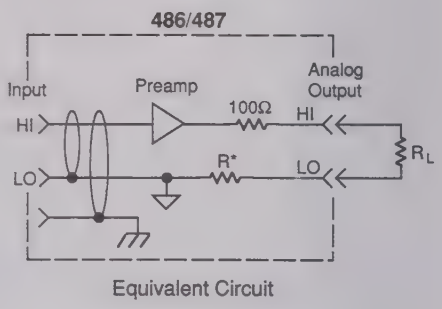
CAUTION

To prevent damage to the instrument, adhere to the following precautions when floating the input above chassis ground:

1. Do not connect ANALOG OUTPUT LO to CHASSIS. If there is a ground link installed at the rear panel binding posts, remove it.
2. Make sure that any monitoring instrument connected to the analog output is floating.

Paragraph 3.16.8 explains the precautions for floating measurements in more detail.





Equivalent Circuit

R* = 1kΩ for protection purposes, and virtually 0Ω for accuracy considerations.

Figure 3-14. Typical Analog Output Connections

Table 3-9. Typical Analog Output Values

486/487 Range	Applied Signal	Analog Output Level
2nA	1.2nA	1.2V
20nA	21nA	2.1V
200nA	12nA	0.12V
2µA	1.2µA	1.2V
20µA	19µA	1.9V
200µA	85µA	0.85V
2mA	2mA	2V

3.13 TALK-ONLY

In talk-only, the Model 486/487 will talk continuously on the IEEE-488 bus and output readings to a listen-only device whenever a measurement conversion occurs. For example, in talk-only, measurement readings from the Model 486/487 will be transmitted to a listen-only printer that is connected to the IEEE-488 bus. Bus connections are covered in paragraph 4.4 of Section 4. While using talk-only, a controller cannot be connected to the IEEE-488 bus.

The listen-only device will not slow down the Model 486/487 measurement rate. For example, after the buffer of a listen-only printer fills, the printer will only accept readings from the Model 486/487 at its print rate. The Model 486/487 continues to take readings at its programmed rate, but sends them only as fast as the printer can accept them.

Perform the following steps to place the Model 486/487 in talk-only:

1. Press and release MENU until the present IEEE-488 selection is displayed. For example, if the IEEE-488 bus address is set to 22, the following message will be displayed:

   IEEE-488 ADDR 22

2. Use the rotary knob, or the ▶ button to display talk-only as follows:

   IEEE-488 TALKONLY

3. To enter the talk-only mode, press MENU. The TALK indicator will turn on.
4. Exit the menu by pressing SHIFT and then EXIT. The instrument will return to the normal measurement display state. Each measurement conversion will be sent over the bus.

NOTE: If the reading source is currently set to B1 (data store readings) from previous IEEE-488 operation (see paragraph 4.2.2 in Section 4), a data store dump to a listen-only device can be performed by placing the instrument in talk-only. If the instrument is in talk-only while data storage is in progress, each reading will be sent to the listen-only device at the programmed interval. If the instrument is placed in talk-only after the data storage is complete, all the stored readings will be sent to the listen-only device as fast as it will accept them.

3.14 OPERATING EXAMPLES

3.14.1 Measuring Current Generated by an LED

A standard light emitting diode (LED) will generate small currents (nanoampere region) when exposed to light. This operating example will use the Model 486 or 487 to measure the current generated by an LED over a range of light intensity, and store the readings in the data store.

Equipment needed:

1 LED
1 Model 7078-ALG Alligator Cable (supplied)

Procedure:

NOTE
Step 1 will return the instrument to factory default conditions. In that state, filter will be enabled (DIG+AN), zero check will be enabled, and autorange will be enabled.

1. Perform the following steps to perform factory initialization:
   A. Press and release MENU until the following message is displayed:

      DEFAULTS OK

   B. Use the rotary knob to display the following message:

      DEFAULTS FACTORY

   C. Press MENU to perform factory initialization.
2. Connect the LED to the Model 486/487 as shown in Figure 3-15.
3. Zero correct the Model 486/487 by pressing SHIFT and then CORRECT.
4. Place the LED, with the test cable connected to it, in a dark place (i.e. desk drawer, or a in a box).
5. Disable ZERO CHECK.
6. Verify that the reading on the display is around 1pA or less. The LED should generate virtually 0A in a dark environment.
7. Configure the data store of the Model 486/487 as follows:
   A. Press and release SETUP until the trigger interval is displayed. Use the ◀ and ▶ keys, and the

rotary knob to display an interval of 1/2 seconds as follows:

TRIG INTVL 000.500

B. Enter the displayed trigger interval by pressing SHIFT and then SETUP.
C. Press MENU and use the rotary knob to display the following message:

DATA STORE YES

D. Press MENU and use the ◀ and ▶ keys to display a buffer size of 50 readings as shown:

BUFFERSIZE 050 RDGS

E. Arm the data store by pressing MENU. The "data store armed" indicator (*) will be displayed.

NOTE

When triggered, the data store will store 50 readings at an interval rate of 1/2 seconds. This will give you approximately 25 seconds to move the LED gradually from the dark environment to a bright light source (lamp or flashlight).

8. To start the data storage process, press the flashing TRIGGER key.
9. After allowing a few seconds to acquire readings in the dark environment, gradually move the LED from the dark towards a bright light source. Time the transition from dark to bright light such that the last few seconds of data storage are performed at peak light conditions.
10. Data storage will be complete when the displayed "*" turns off.
11. Perform the following steps to recall stored data:
    A. Press and release MENU until the following message is displayed:

    DATA RECL NO

    B. Use the rotary knob to display the following message:

    DATA RECL YES

    C. Press MENU. The first reading (at memory location 001) will be displayed. Since this measurement was performed in the dark, the following reading could result:

    0.00074 nA LOC 001

    D. Examine the readings stored in the other memory locations by using the rotary knob. Turning the knob clockwise increments the memory locations. Turning the knob counter-clockwise past location 001 displays the minimum and maximum readings stored in the buffer. For this test, the following maximum and minimum readings could result:

    022.106 nA LOC MAX
    –0.36250 nA LOC MIN

12. To disable data recall, press SHIFT and then MENU.

For this example, you would expect the current to increase as the source of light increases. In general, the test data should support this. However, because this test was not conducted under ideal conditions, electric fields due to a lack of shielding and induced currents due to cable flexing when moving the LED most likely caused some "undesirable" readings.

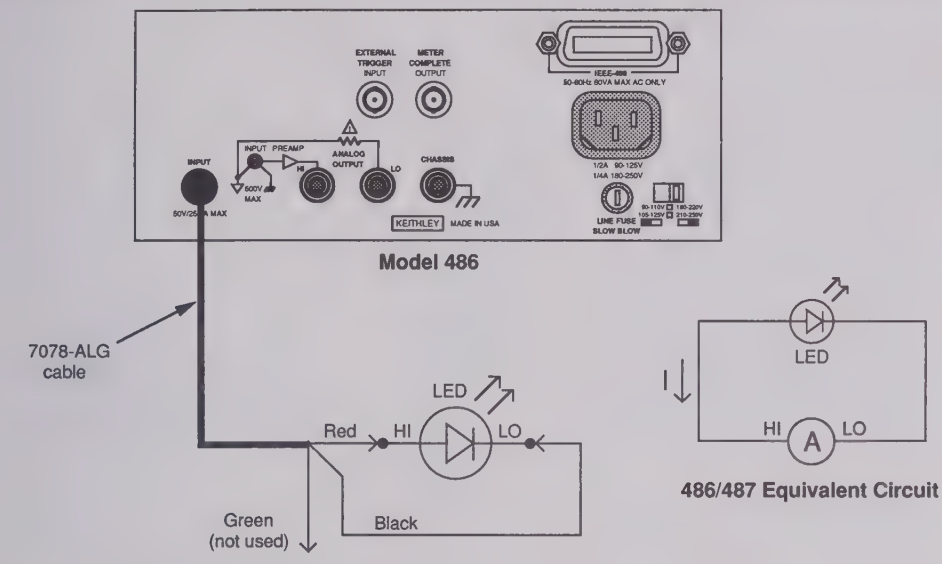


Figure 3-15. Setup for Measure LED Current

3.14.2 Resistivity Tests (Model 487)

Resistivity of insulators can be determined by applying high voltage to the material under test and measuring the subsequent current.

The following operating example will determine the volume or surface resistivity of paper using the V/I ohms function of the Model 487 and the Model 6105 Resistivity Adapter. Be sure to read the instruction manual for the Model 6105 before performing this test.

Equipment Needed:

Model 6105 Resistivity Adapter
Model 6147 2-Slot Triax to BNC Adapter (supplied with Model 6105)
Model 4801 BNC to BNC Input Cable (supplied with Model 6105)
Model 6171 3-Slot Triax to 2-Lug Triax Adapter

Procedure:

NOTE
Step 1 will return the instrument to factory default conditions. In that state, filter will be enabled (DIG+AN), zero check will be enabled, and autorange will be enabled.

1. Perform the following steps to perform factory initialization:
   A. Press and release MENU until the following message is displayed:

      DEFAULTS OK

   B. Use the rotary knob to display the following message:

      DEFAULTS FACTORY

   C. Press MENU to perform factory initialization.
2. Connect the Model 487 to the Model 6105 as shown in Figure 3-16. Notice that with the Model 487 configured as shown, an internal 1kΩ resistor appears in series with the paper sample. This 1kΩ resistance is insignificant when compared to the resistance of the paper sample, and thus, will not affect the results of this test.
3. Perform one of the following steps (A or B) to configure the Model 6105 for the desired test:
   A. To test surface resistivity, configure the Model 6105 as shown in Figure 3-17. The banana plug cable from the electrode is connected to the banana jack labeled "SURFACE". The shorting plug is installed in the other two banana jacks.
   B. To test volume resistivity, configure the Model 6105 as shown in Figure 3-18. The banana plug cable from the electrode is connected to the banana jack labeled "VOLUME". The shorting plug is installed in the other two banana jacks.

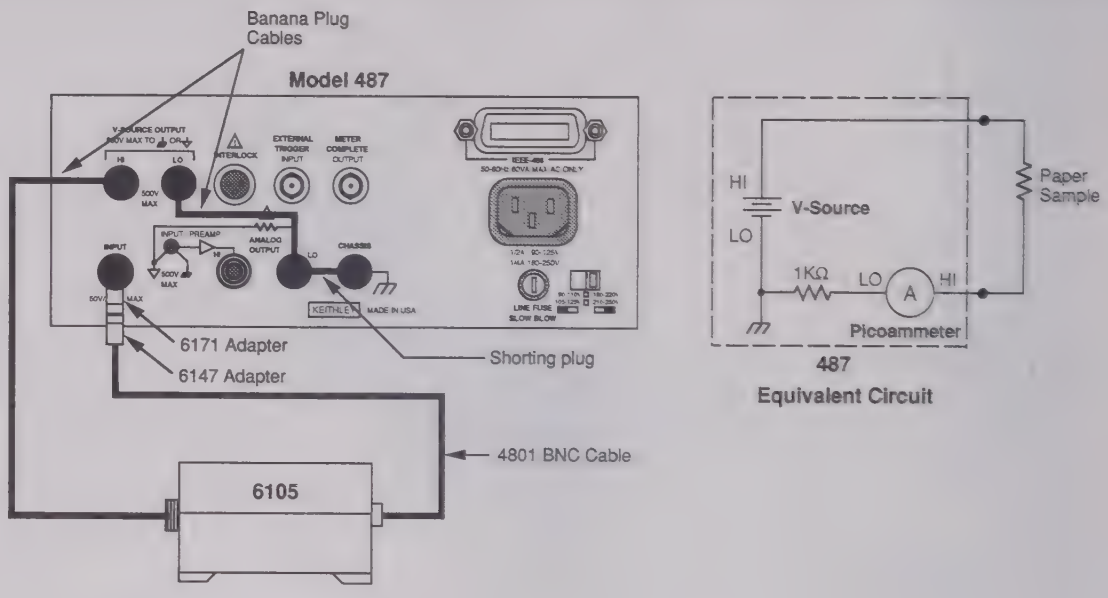


Figure 3-16. Connections for Resistivity Test

4. For shipping and during storage, two screw fasteners are used to secure the electrodes. Remove these two fasteners if they are currently installed.
5. As shown in Figure 3-17 and Figure 3-18, position the paper sample between the electrodes. Make sure there are no conductive paths between the electrodes other than through the sample. The electrodes must not touch anything except the sample.
6. Close the Model 6105 cover and secure the latch. An interlock switch disconnects power from the sample if the cover is not completely closed.

WARNING

The following steps will apply hazardous voltage, that could cause severe injury or death. Exercise extreme caution when the V-Source of the Model 487 is in operate.

7. With the V-source of the Model 487 in standby (OPERATE indicator off), use the ◀ and ▶ keys, and the rotary knob to set the V-source to 500.00V.
8. Select the V/I ohms function by pressing SHIFT and then OHMS. The ZERO CHECK indicator will start flashing.
9. Place the V-source of the Model 487 in operate by pressing OPERATE. 500V will be applied to the paper sample.

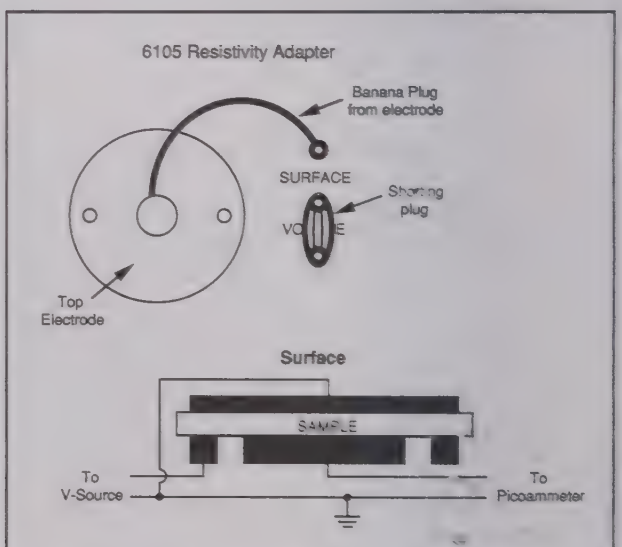


Figure 3-17. Configuration for Surface Resistivity

10. On the Model 487, press ZERO CHECK to disable zero check and allow one minute to electrify the sample.
11. After one minute electrification time, record the resistance measurement (R_M) from the display of the Model 487.
12. On the Model 487, enable zero check and place the V-Source in standby.

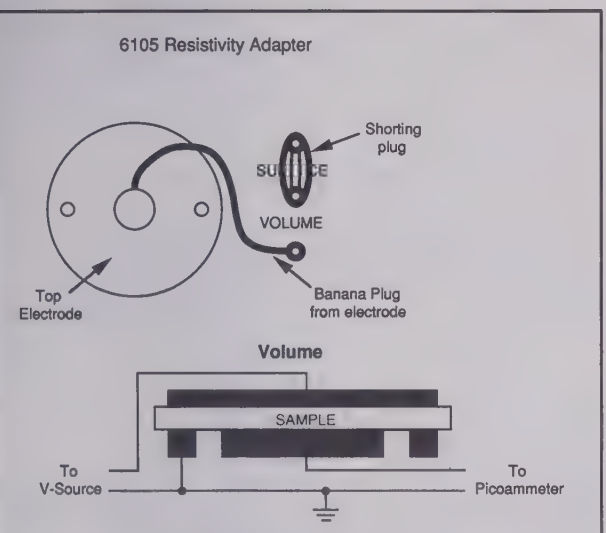


Figure 3-18. Configuration for Volume Resistivity

13. Calculate the resistivity of the paper sample as follows:
    A. If the Model 6105 is configured for surface resistivity, perform the following calculation:

$$\sigma = 53.4\ R_M \text{ ohms}$$

where; σ is the surface resistivity of the sample;
53.4 is a constant based on the physical dimensions of the electrodes of the Model 6105;
R_M is the V/I ohms reading from the Model 487.

For example, if the reading on the Model 487 (R_M) is 90GΩ (typical for plain paper), the surface resistivity of the paper sample is calculated as follows:

$$\sigma = 53.4 \times 90G\Omega = 4.8 \times 10^{12}\Omega$$

    B. If the Model 6105 is configured for volume resistivity, perform one of the following calculations:

$$p = \frac{3.53}{t_i} R_M \text{ ohm-inches}$$

$$p = \frac{22.9}{t_c} R_M \text{ ohm-centimeter}$$

where; p is the volume resistivity of the sample;
3.53 is a constant based on the physical dimensions (in inches) of the electrodes of the Model 6105;
22.9 is a constant based on the physical dimensions (in centimeters) of the electrodes of the Model 6105;
R_M is the V/I ohms reading from the Model 487;
t_i is the thickness of the sample in inches;
t_c is the thickness of the sample in centimeters.

For example, if the reading on the Model 487 (R_M) is 90GΩ and the thickness of the paper sample is 5 mils, the volume resistivity is calculated as follows:

$$p = \frac{3.53}{0.005}\ 90G\Omega = 6.35 \times 10^{13} \text{ ohm-inches}$$

3.15 SOURCE VOLTAGE/MEASURE CURRENT (Model 487)

For V/I ohms measurements (see paragraph 3.7), the Model 487 is configured to source voltage and measure current. The following paragraphs will summarize how to use the Model 487 in other test systems that require the instrument to source voltage and measure current (Source V/Measure I).

NOTE
An operating example to perform resistivity tests is contained in paragraph 3.14.2.

3.15.1 Basic Source V/Measure I Configurations

The most common configuration to source V and measure I, as used for V/I ohms measurements, is shown in Figure 3-10. In this configuration the V-source and picoammeter are separately connected to the test fixture.

An alternate configuration to source V and measure I is shown in Figure 3-19. The V-Source is connected in series to the picoammeter at the rear panel of the Model 486 (V-SOURCE LO connected to ANALOG OUTPUT LO). In this configuration, the Model 487 looks like a source-measure unit. Connections to the test fixture are similar to those of standard source measure units, such as the

Keithley Models 236 and 237. Note that if connections at the V-Source output are reversed, output low would be connected to the test fixture and output high would be connected to input common (LO) of the picoammeter. In this case, a positive (+) V-source output will result with negative (–) current readings on the Model 487.

There is a consideration to using the source-measure unit configuration. Internally, there is a 1kΩ resistor between analog output low and input low of the picoammeter. This 1kΩ resistor appears between the V-source and picoammeter as shown in the equivalent circuit in Figure 3-19. Since this 1kΩ resistor is in series with the DUT, loading effects could be significant for low impedance DUTs. Thus, the source-measure unit configuration should only be used for high impedance DUTs. For example, for a device with an impedance of 1MΩ, the error due to loading will be approximately 0.1%.

CAUTION

To prevent damage to the instrument, adhere to the following precautions when floating the input above chassis ground:

1. Do not connect ANALOG OUTPUT LO to CHASSIS. If there is a ground link installed at the rear panel binding posts, remove it.
2. Make sure that any monitoring instrument connected to the analog output is floating.

Paragraph 3.16.8 explains the precautions for floating measurements in more detail.

WARNING

Do not connect the interlock of a Model 487 to the interlock of another instrument. The interlock of the Model 487 is designed to be connected to a single-pole interlock switch of a test fixture. If connecting two or more Model 487s to a single test fixture, an isolated interlock switch for each instrument is required. Connecting multiple instrument interlocks to the same switch could cause failure of the safety interlock system.

3.15.2 Testing 2-Terminal Devices

The Model 487 is ideal for sourcing voltage and measuring current to test voltage co-efficients of resistors, leakage current of capacitors, and reverse current of diodes. Generally, these tests are performed on high impedance devices allowing either source V measure I configuration to be used. (Figure 3-10 or Figure 3-19).

NOTE

For the following test examples, use Figure 3-10 or Figure 3-19 as the circuit configuration. The device under test (DUT) is shown installed in the Keithley Model 8002A test fixture.

Voltage Coefficient Tests of Resistors

High megohm resistors often exhibit a change in resistance with applied voltage. This resistance change is characterized as the voltage coefficient.

To determine voltage coefficient of a resistor, two V/I ohms measurements at two different voltage values will be required. The voltage coefficient in %/V can then be calculated as follows:

$$\text{Voltage Coefficient (\%/V)} = \frac{100(R_2 - R_1)}{R_1 V}$$

where; R_1 is the measured resistance with the first applied voltage.
R_2 is the measured resistance with the second applied voltage.
V is the difference between the two applied voltages.

Example: Assume that the following values are obtained:

$R_1 = 1.01 \times 10^{10}\Omega$
$R_2 = 1 \times 10^{10}\Omega$
$V = 5V$

The resulting voltage coefficient is:

$$\text{Voltage coefficient (\%/V)} = \frac{100\ (1 \times 10^8)}{1 \times 10^{10}(5)} = 0.2\%/V$$

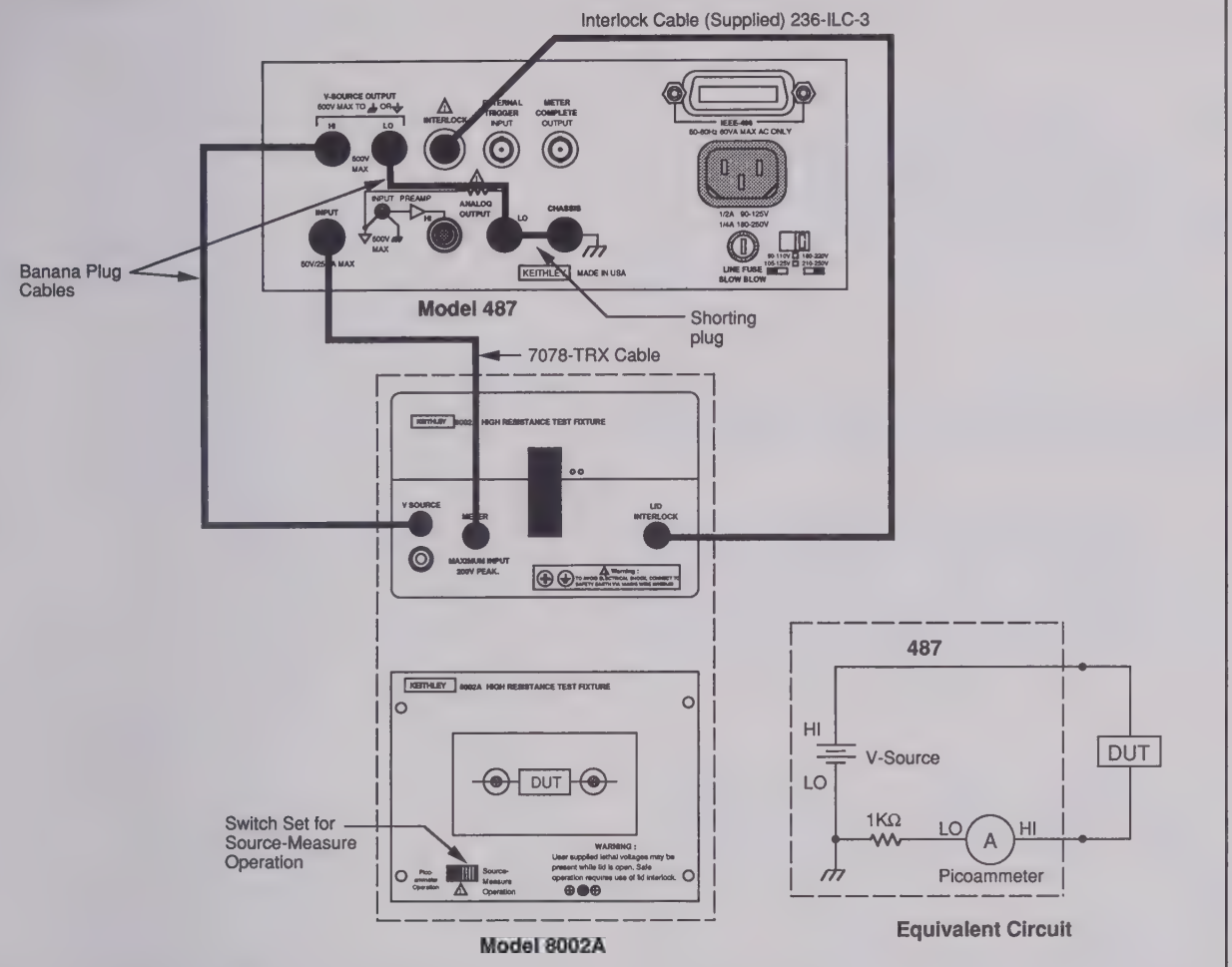


Figure 3-19. Source-Measure Unit Configuration

Note that the voltage coefficient of a particular device may apply only across the selected voltage range and may vary with different voltage increments in the same approximate range.

Capacitor Leakage Tests

An important parameter associated with capacitors is leakage current. The amount of leakage current in a capacitor depends both on the type of dielectric as well as the applied voltage. With a test voltage of 100V, for example, ceramic dielectric capacitors have typical leakage currents in the nA to pA range. By using the V/I ohms function, the leakage current measurement can be automatically converted into the insulation resistance value.

When measuring leakage currents on capacitors, stability and noise performance can be maintained by adding a resistor in series with the capacitor under test. The value of this resistor should be around 1MΩ. For larger capacitor values (>1μF), the value of the series limiting resistor can be made lower in order to improve settling times; however, values below 10kΩ are not generally recommended.

After the voltage is applied to the capacitor, the device must be allowed to charge fully before the measurement can be made. Otherwise, an erroneous current, with a much higher value will be measured. The time period during which the capacitor charges is often termed the "soak" time. A typical soak time is 7 time constants, or

7RC, which would allow settling to less than 0.1% of final value.

WARNING
Hazardous voltage may be present on the capacitor leads after performing this test. Discharge the capacitor before removing it from the test fixture.

Diode Reverse Current Test

The reverse current of a diode can be checked using the Model 487 to source voltage and measure current.

To perform this test, the diode must be reverse-biased by programming the V-Source to apply a positive (+) voltage to the cathode of the diode (anode to V-Source common). Forward biasing the diode will, in most cases, cause the Model 487 to go into I-limit.

To check the reverse current of a 1N3952 germanium diode, set the V-source of the Model 487 to apply +4.5 V to the cathode of the diode. The measured reverse current displayed on the Model 487 should be approximately 4μA.

3.16 MEASUREMENT CONSIDERATIONS

The Model 486/487 is a highly sensitive instrument that can measure very low current levels. At these low signal levels, a number of factors can affect a measurement. Some considerations when making measurements with the Model 486/487 are discussed in the following paragraphs.

3.16.1 Source Resistance

As shown in Table 3-10, a minimum value of source resistance (R_S) is recommended for each current range. The reason for this can be understood by examining Figure 3-20. Considering the effects on low frequency noise and drift, C_S and C_F can momentarily be ignored.

Input amplifier noise and drift appearing at the output can be calculated as follows:

Table 3-10. Minimum Recommended

Range	Minimum Source Resistance (RS)
2nA	1GΩ
20nA	100MΩ
200nA	10MΩ
2μA	1MΩ
20μA	100kΩ
200μA	10kΩ
2mA	1kΩ

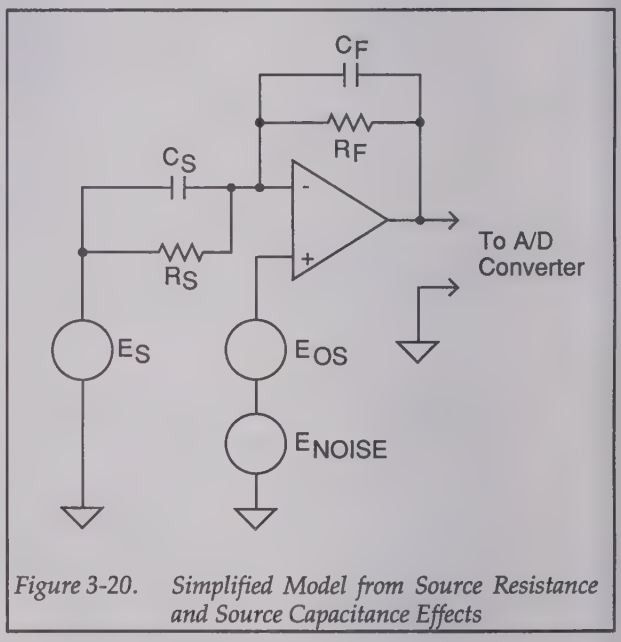


Figure 3-20. Simplified Model from Source Resistance and Source Capacitance Effects

Equation 1

$$\text{Output } E_{NOISE} = \text{Input } E_{NOISE} \times \left(1 + \frac{R_F}{R_S}\right)$$

Thus, it is clear that as long as $R_S >> R_F$, Output E_{NOISE} = Input E_{NOISE}. When $R_F = R_S$, Output E_{NOISE} = 2 × Input E_{NOISE}.

The same applies for E_{OS}. The Model 486/487 will typically show insignificant degradation in displayed performance with the noise gain of 2 resulting from allowing $R_S = R_F$. Amplifier E_{OS} can be nulled by using the relative feature. The temperature coefficient of E_{OS} is <30μV/°C. These numbers can be used with Equation (1) to determine expected displayed noise/drift given any source re-

sistance. Note also the values given in Table 3-11 for minimum source resistance also represent the value of R_F on that range.

3.16.2 Source Capacitance

Very high input capacitance (C_S) may increase noise and induce instrument instability. The noise gain of the measurement circuit can be found from:

Equation 2

$$\text{Output } E_{NOISE} = \text{Input } E_{NOISE} \times \left(1 + \frac{Z_F}{Z_S}\right)$$

$$\text{where: } Z_F = \frac{R_F}{\sqrt{(2\pi f R_F C_F)^2 + 1}}$$

$$Z_S = \frac{R_S}{\sqrt{(2\pi f R_S C_S)^2 + 1}}$$

Clearly as f→0, Equation 2 reduces to Equation 1 (see previous paragraph).

The frequency of interest is 0.1 to 300Hz which is the bandwidth of the A/D converter. The values of C_F are listed in Table 3-11.

Table 3-11. Feedback Capacitor (C_F) Values

Range	Feedback Capacitor (C_F)	
	Analog Filter Disabled	Analog Filter Enabled
2nA	4pF	25.3pF
20nA	13.3pF	13.3pF
200nA	25.3pF	47.3pF
2µA	103.3pF	125.3pF
20µA	333.3pF	355.3pF
200µA	3633.3pF	3655.3pF
2mA	10333.3pF	10355.3pF

In general, as C_S becomes larger, the noise gain becomes larger. An application of where C_S is very high is leakage measurements of capacitors. In this case, Input E_{NOISE} must include the effects of the voltage source (E_S) used to bias the capacitor (any noise in the source voltage will increase the input noise).

When measuring leakage currents on capacitors larger than 10,000pF, stability and noise performance can be maintained by adding a resistor in series with the capacitor under test. The value of this resistor should be around 1MΩ. For large capacitor values (>1µF), the value of the series limiting resistor can be made lower in order to improve settling times; however, values below 10kΩ are not generally recommended.

The resistor is not critical in terms of tolerance or stability. Any carbon composition resistor will prove adequate.

3.16.3 Triboelectric and Pizoelectric Effects

Unwanted currents may be generated due to triboelectric and pizoelectric effects, and will subsequently be measured by the Model 486/487.

Triboelectric Effects

Triboelectric currents are generated by charges created between a conductor and an insulator due to friction. Here, electrons rub off the conductor and create a charge imbalance that causes the current flow. A typical example would be electrical currents generated by insulators and conductors rubbing together in a coaxial cable (see Figure 3-21).

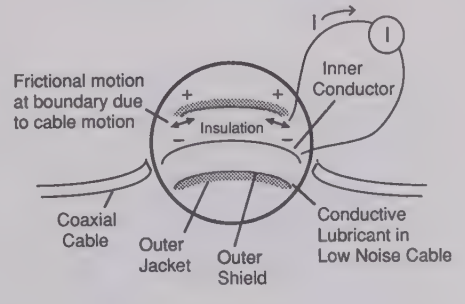


Figure 3-21. Triboelectric Effect

"Low-noise" cable greatly reduces this effect. It typically uses an inner insulator of polyethylene coated with graphite underneath the outer shield. The graphite pro-

vides lubrication and a conducting equipotential cylinder to equalize charges and minimize charge generated by frictional effects of cable movement. However, even low-noise cable creates some noise when subjected to vibration and expansion or contraction, so all connections should be kept short, away from temperature changes (which would create thermal expansion forces), and preferably supported by taping the cable to a nonvibrating surface such as a wall, bench, or rigid pole.

Other solutions to movement and vibration problems include:

- Removal or mechanical decoupling of the source of vibration. Motors, pumps and other electromechanical devices are the usual sources.
- Stabilization of the test hookup. Securely mount or tie down electronic components, wires and cables. Shielding should be sturdy.

Triboelectric effects can also occur in other insulators and conductors which touch each other. Therefore, it is important to minimize contact between insulators as well as conductors in constructing test fixtures and connections for low current and high impedance.

Piezoelectric Effects

Piezoelectric currents are generated when mechanical stress is applied to certain insulating materials. The effect occurs in ceramics and other crystalline materials, as well as some plastics used for insulated terminals and interconnecting hardware. An example of a terminal with a piezoelectric insulator is shown in Figure 3-22.

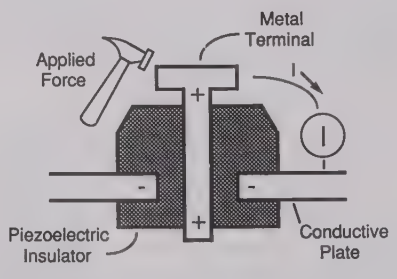


Figure 3-22. Piezoelectric Effect

To minimize the current due to this effect, it is important to remove mechanical stresses from the insulator and use insulating materials which have minimal piezoelectric effects, such as saphire, Teflon® or PVC.

3.16.4 Electrostatic Interference

Electrostatic interference occurs when an electrically charged object is brought near an uncharged object, thus inducing a charge on the previously uncharged object. Usually, the effects of such electrostatic action are not noticeable because low impedance levels allow the induced charge to dissipate quickly. However, high impedance levels of many measurements do not allow these charges to decay rapidly, and erroneous or unstable readings may be caused in the following ways:

1. Dc electrostatic fields can cause undetected errors or noise in the reading.
2. Ac electrostatic fields can cause errors by driving the amplifier into saturation, or through rectification that produces dc errors.

Electrostatic interference is first recognizable when hand or body movements near the experiment cause fluctuations in the reading. Pick up from ac fields can also be detected by observing the output on an oscilloscope. Line frequency signals on the output are an indication that electrostatic interference is present.

Means of minimizing electrostatic interference include:

1. Shielding. Possibilities include: a shielded room, a shielded booth, shielding the sensitive circuit (test fixture), and using shielded cable. The shield should always be connected to a solid connector that is connected to signal low. Note, however, that shielding can increase capacitance, possibly slowing down response time.
2. Reduction of electrostatic fields. Moving power lines or other sources away from the experiment reduces the amount of electrostatic interference seen

3.16.5 Thermal EMFs

Thermal EMFs are small electric potentials generated by differences in temperature at the junction of two dissimilar metals. Low thermal connections should be used whenever thermal EMFs are known to be a problem. Crimped copper to copper connections can be used to minimize these effects.

3.16.6 Radio Frequency Interference

Radio frequency interference (RFI) is a general term frequently used to describe electromagnetic interference over a wide range of frequencies across the spectrum. RFI can be especially troublesome at low signal levels, but it may also affect higher level measurements in extreme cases.

RFI can be caused by steady-state sources such as TV or radio broadcast signals, or it can result from impulse sources, as in the case of arcing in high voltage environments. In either case, the effect on instrument performance can be considerable, if enough of the unwanted signal is present. The effects of RFI can often be seen as an unusually large offset, or, in the case of impulse sources, sudden, erratic variations in the reading.

The most convenient method to minimize the effects of RFI is to use the FILTER feature of the instrument. A detrimental affect of filtering is that overall measurement speed is decreased.

Other methods can be used to minimize the effects of RFI. The most obvious method is to keep the instrument and experiment as far away from the RFI source as possible. Shielding the instrument, experiment, and test leads will often reduce RFI to an acceptable level. In extreme cases, a specially constructed screen room may be necessary to sufficiently attenuate the troublesome signal.

3.16.7 Ground Loops

Ground loops that occur in multiple-instrument test set–ups can create error signals that cause erratic or erroneous measurements. The configuration shown in Figure 3-23 introduces errors in two ways. Large ground currents flowing in one of the wires will encounter small resistances, either in the wires, or at the connecting points. This small resistance results in voltage drops that can affect the measurement. Even if the ground loop current is small, magnetic flux cutting across a large loop formed by the ground leads can induce sufficient voltages to disturb sensitive measurements.

To prevent ground loops, test system common should be connected to earth ground at only a single point, as shown in Figure 3-24. Note that circuit common is connected to earth ground only at Instrument B (via the ground link). The ground link for Instrument A has been

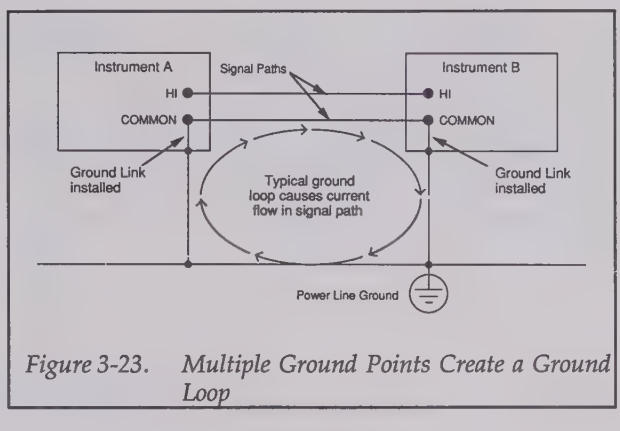


Figure 3-23. Multiple Ground Points Create a Ground Loop

removed. Experimentation is the best way to determine an acceptable arrangement. For this purpose, measuring instruments should be placed on their lowest ranges. The configuration that results in the lowest noise signal is the one that should be used.

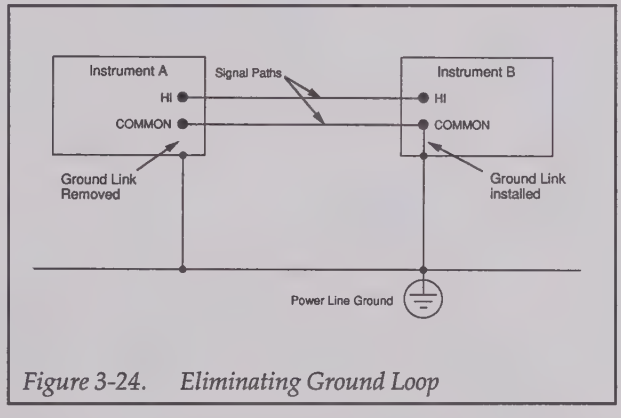


Figure 3-24. Eliminating Ground Loop

3.16.8 Floating Measurements

CAUTION

To prevent damage to the instrument, adhere to the following precautions when floating the input above chassis ground:

1. Do not connect ANALOG OUTPUT LO to CHASSIS. If there is a ground link installed at the rear panel binding posts, remove it.
2. Make sure that any monitoring instrument connected to the analog output is floating.

The circuit connected to the input of the Model 486/487 in Figure 3-25 shows a typical configuration to make

floating measurements. A problem occurs when ANALOG OUTPUT LO is connected to chassis ground. As shown in the illustration, connecting ANALOG OUTPUT LO to chassis ground will provide a current path for the voltage source through the internal fusible resistor R203. In this configuration, a voltage source with high current capabilities could damage the resistor. For example, if voltage source (E) is set to 100V and has a 100mA limit, current through R203 could be 100mA (100V/1kΩ=100mA) damaging the 1/2W fusible resistor.

If the V-Source of the Model 487 is used to make floating measurements, damage to R203 cannot occur because of the 2.5mA limit. However, the measurement could be compromised if the V-Source is forced into current limit.

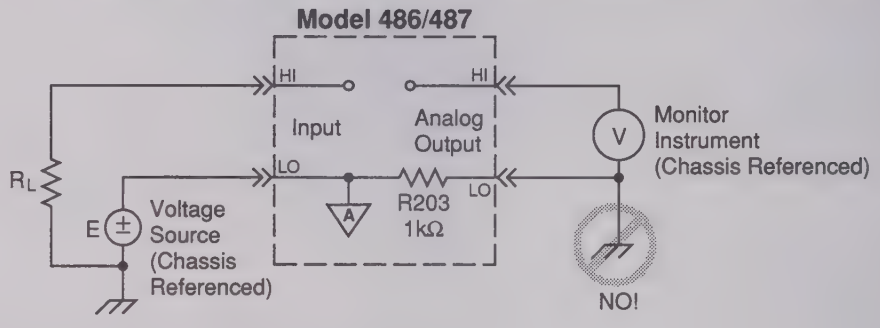


Figure 3-25. Improper Method to make Floating Measurements

SECTION 4
IEEE-488 Reference

4.1 INTRODUCTION

The IEEE-488 bus is an instrumentation data bus with hardware and programming standards originally adopted by the IEEE (Institute of Electrical and Electronic Engineers) in 1975 and given the IEEE-488 designation. In 1978, standards were upgraded into the IEEE-488-1978 standards. The Models 486 and 487 conform to these standards.

This section contains reference information on programming the Model 486/487 over the IEEE-488 bus. Detailed instructions for all programmable functions are included, however, information concerning operating modes presented elsewhere is not repeated. Refer to Sections 2 and 3 for information not found in this section.

Additional information on the IEEE-488 bus is located in the appendices.

4.2 DEVICE-DEPENDENT COMMAND PROGRAMMING

IEEE-488 device-dependent commands are the most important commands associated with instrument programming because they control most instrument operating modes. The IEEE-488 bus actually treats these commands as data, in that they are sent with the ATN line false.

Most Model 486/487 front panel operations (such as range selection) as well as some operations not available from the front panel (like SRQ and terminator) can be programmed with these commands.

Command Syntax — Each command is made up of a single ASCII capital letter followed by one or more numbers or letters representing an option or numeric parameter of that command. For example, the integration time can be set over the bus by sending the letter "S" followed by a number representing the integration time option. S0X would be sent to program a 1.6msec integration time. Sending a command without an option (such as RX) is the same as not sending a command. However, it will take time to process the command.

If a command appears more than once in an X-terminated string, only the last occurrence of the command is executed - the others are ignored.

Multiple Options — Some commands have two or more options that must be separated by commas. For example, a V5,0,1X command programs the voltage source of the Model 487. In this case, the 5 is the value of the voltage source (+5V), 0 is the voltage source range (50V), and the 1 is the current limit option (2mA).

Options of a multiple option command may be defaulted as demonstrated in the following examples:

V10X	Set V–source to 10V. Range and I-limit will default to currently programmed parameters.
V60,1X	Set V-source to 60V on the 500V range, and default I-limit.
V,0X	Default V-source, select 50V range, and default I-limit.
V,,0X	Default V-source, default range, and set I-limit to 25µA.

Multiple Commands — A number of commands can be grouped together in one command string, which is generally terminated by the "X" character. This character tells the instrument to execute the command or command string, as described in paragraph 4.2.22. Commands sent without the execute character will not be executed at that particular time, but they will be stored within an internal command buffer for later execution when the execute character is finally received.

Invalid Commands — If an invalid command is sent as part of the command string, no commands in the string will be executed. Under these conditions, the instrument will display a front panel error message (IDDC or ID-

DCO) and it can be programmed to generate an SRQ (Service Request), as discussed in paragraph 4.2.11. Commands are checked as they are received. When an illegal command is received, all other commands since the previous X and until the next X are ignored.

Some typical examples of valid command strings include:

R0X	Single command followed by execute command.
Y4S0P0X	Multiple command string.
Z 1X	Space is ignored
V4,0,0X	Multiple-option command string (options separated by commas).

Typical invalid command strings include:

E1X	Invalid command, as E is not one of the instrument's valid commands.
K6X	Invalid command option because 6 is not an option of the K command.
N600X	Invalid parameter (buffer size cannot exceed 512).
Z2.001X	Multiple-option command without the necessary separating commas.

Device-dependent Command Summary — All Model 486/487 device-dependent commands are summarized in Table 4-1, which also lists respective paragraphs where more detailed information on each command may be found.

Table 4-1. Device-dependent Command Summary

Mode	Command	Description	Para.
Display Intensity	A0	Normal display	4.2.1
	A1	Dim display	
	A2	Turn display off	
Reading Source	B0	Readings from A/D	4.2.2
	B1	Single reading from data store	
	B2	All readings from data store	
	B3	Maximum reading from data store	
	B4	Minimum reading from data store	
Zero Check and Correct	C0	Disable zero check	4.2.3
	C1	Enable zero check	
	C2	Enable zero check and perform zero correction	
Display	Da	Display up to 18 character (a) message	4.2.4
	D	Cancel display mode	
V/I Ohms	F0	Disable V/I ohms	4.2.5
	F1	Enable V/I ohms	
Data Format	G0	ASCII rdgs with prefix	4.2.6
	G1	ASCII rdgs without prefix	
	G2	ASCII rdgs and buffer locations with prefix	
	G3	ASCII rdgs and buffer locations without prefix	
	G4	Binary rdgs: IEEE Std 754 single-precision, bytes reversed for Intel CPUs	
	G5	Binary rdgs: IEEE Std 754 single-precision, bytes in normal order for Motorola CPUs	

Device-dependent Command Summary (Cont.)

Mode	Command	Description	Para.
Data Format (Cont).	G6	Binary rdgs: counts and exponent, bytes reversed for Intel CPUs	
	G7	Binary rdgs: counts and exponent, bytes in normal order for Motorola CPUs	
Hit Control	H1	Hit DISPLAY INTENSITY key	4.2.7
	H2	Hit LOCAL key	
	H3	Hit SHIFT key	
	H4	Hit MENU key	
	H5	Hit ZERO CHECK key	
	H6	Hit FILTER key	
	H7	Hit RANGE V key	
	H8	Hit REL key	
	H9	Hit RANGE A key	
	H10	Hit SETUP key	
	H11	Hit TRIGGER key	
	H12	Hit OPERATE key (487)	
	H13	Hit PRESET key (487)	
	H14	Hit ◀	
	H15	Hit ▶	
	H16	Hit Rotary Knob counterclockwise	
	H17	Hit Rotary Knob clockwise	
Self-Test	J0	Perform ROM/RAM self-test	4.2.8
	J1	Perform display and ROM/RAM self-test	
EOI and Bus Hold-off	K0	Enable EOI and bus hold-off on X	4.2.9
	K1	Disable EOI, enable bus hold-off on X	
	K2	Enable EOI, disable bus hold-off on X	
	K3	Disable both EOI and bus hold-off on X	
Default Conditions or Calibration	L0	Return to factory default conditions and save (L1)	4.2.10
	L1	Save present states as default conditions	
	L2	Return to saved default conditions	
	L3,v	Calibrate present measurement range using "v"; v = –2E–3 to +2E–3 amps	
	L4	Calibrate zero on present voltage source range (Model 487 only)	
	L5	Calibrate full scale on present voltage source range (Model 487 only)	
	L6	Prepare to calibrate present voltage source range (Model 487 only)	
SRQ	M0	Disable SRQ	4.2.11
	M1	Reading overflow	
	M2	Data store full	
	M4	Data store half full	
	M8	Reading done	
	M16	Ready	
	M32	Error	
	M128	Voltage Source Error (Model 487 only)	
Data Store	O0	Arm data store; wrap around operation	4.2.12
	On	Arm data store; set buffer size "n" where n = 1 to 512	
Operate	N0	Place voltage source in standby	4.2.13
	N1	Place voltage source in operate	

Device-dependent Command Summary (Cont.)

Mode	Command	Description	Para.
Filters	P0	Disable digital and analog filters	
	P1	Enable digital filter; disable analog filter	
	P2	Disable digital filter; enable analog filter	
	P3	Enable digital and analog filters	
Interval	Q0	175msec (factory default)	4.2.15
	Qn	Set to "n" seconds. n = 0.010sec to 999.999sec	
Range	R0	Enable autorange	4.2.16
	R1	Select 2nA range	
	R2	Select 20nA range	
	R3	Select 200nA range	
	R4	Select 2µA range	
	R5	Select 20µA range	
	R6	Select 200µA range	
	R7	Select 2mA range	
	R8	No range	
	R9	No range	
	R10	Disable autorange	
Integration	S0	Fast integration; 1.6msec at 4-1/2 digit resolution	4.2.17
	S1	Line cycle integration; 16.67msec (60Hz) or 20msec (50Hz) at 5-1/2 digit resolution	
Trigger	T0	Multiple on Talk	4.2.18
	T1	One-shot on Talk	
	T2	Multiple on GET	
	T3	One-shot on GET	
	T4	Multiple on X	
	T5	One-shot on X	
	T6	Multiple on External Trigger	
	T7	One-shot on External Trigger	
	T8	Multiple on Operate (487)	
	T9	One-shot on Operate (487)	
Status	U0	Send machine status word	4.2.19
	U1	Send error status word	
	U2	Send model number and firmware revision	
	U3	Send calibration value	
	U4	Send interval	
	U5	Send delay	
	U6	Send relative value for current	
	U7	Send relative value for V/I ohms	
	U8	Send voltage source value (487)	
	U9	Send voltage source error status word (487)	
Voltage Source (487)	Vn,r,l	Specify voltage source level "n" in volts, range "r" and limit "l" n: –505 to +505 r: 0 = 50V range; 1 = 500V range l: 0 = 20µA limit; 1 = 2mA limit	4.2.20

Device-dependent Command Summary (Cont.)

Mode	Command	Description	Para.
Delay	Wn	Delay trigger "n" seconds; n = 0 to 999.999sec	4.2.21
Execute	X	Execute other device-dependent commands	4.2.22
Terminator	Y0	CR LF	4.2.23
	Y1	LF CR	
	Y2	CR	
	Y3	LF	
	Y4	None	
Relative	Z0	Disable relative	4.2.24
	Z1	Enable relative using present reading as baseline	
	Z2,V	Enable relative using "v" as baseline; v = –2E–3 to +2E–3 amps for current, v = 0Ω to 50.5E16Ω for V/I ohms	
	Z3	Enable relative using the baseline previously defined	

4.2.1 A — Display Intensity

Purpose

To control the brightness of the display and front panel indicator lights.

Format

An

Parameters

A0 Select normal display
A1 Select dim display
A2 Turn display off

Default

Upon power-up, or after receiving a DCL or SDC command, the instrument returns to the display intensity that was saved as the default condition.

Description

Control of display intensity is useful in applications where the light from the display and indicators could be detrimental to an experiment or test.

The A1 command dims the display and indicators. In low ambient light conditions, the display and indicators are still easily read. The A2 command turns the display and indicators (except POWER) completely off. The power switch indicator remains dimly lit to denote that the instrument is on.

Programming Examples

```
OUTPUT 722; "A1X"      ! Dim the display.
OUTPUT 722; "A2X"      ! Turn the display off.
OUTPUT 722; "A0X"      ! Return display to normal.
```

4.2.2 B — Reading Source

Purpose

To select the source of data (A/D converter or data store) that is transmitted over the bus.

Format

Bn

Parameters

B0 Select A/D converter readings for output to bus
B1 Select single data store reading for output to bus
B2 Select all data store readings for output to bus
B3 Select maximum value reading in data store for output to bus.
B4 Select minimum value reading in data store for output to bus.

Default

Upon power-up or after receiving a DCL or SDC command, the instrument returns to the option of the B command that was saved as the default condition.

Description

With this command, the user has a choice of data from the A/D converter or the buffer (data store). When in B0, A/D readings will be sent. In a continuous trigger mode, readings will be updated at the conversion rate. The B1 command is used to access single readings from the buffer. When the B1 command is sent, subsequent readings will be taken from consecutive buffer locations beginning with the first memory location (001). Once all readings have been taken, the instrument will not send any more readings until another B command is received or another data store operation is started.

The B2 command allows you to dump the entire data store contents to the computer in one operation. Individual ASCII readings will be separated by commas.

The B3 command allows you to send the maximum reading from the data store buffer to the computer, while the B4 command is used to obtain the minimum reading.

Programming Notes

1. The programmed terminator and EOI will be asserted at the end of the complete dump---not after each reading as is the case with B1.
2. In B1 or B2, nothing will be transmitted over the bus until data is stored in the data store.
3. The selected data format (see G command) will apply to each reading sent over the bus to the controller.

Programming Examples

```
10 REMOTE 722
20 OUTPUT 722; "B0X"        ! Select A/D reading mode.
30 ENTER 722; A$            ! Acquire reading from 486/487.
40 PRINT A$                 ! Display reading on CRT.
50 END
```

4.2.3 C — Zero Check and Zero Correct

Purpose Use to cancel any internal offsets that might affect accuracy.

Format Cn

Parameters

C0 Disable zero check
C1 Enable zero check
C2 Enable zero check and perform zero correction

Default Upon power-up, or after receiving a DCL or SDC command, the instrument will return to the state (C0 or C1) that was saved as the default condition.

Description Normal current measurements are performed when zero check is disabled (C0). When zero check is enabled (C1), a large impedance (10MΩ) appears at the input and any internal offset is presented at the output of the input amplifier and measured (see paragraph 3.5.3).

When C2 is sent over the bus, zero check is enabled and zero correction occurs. For zero correction, the measured offset is stored and algebraically subtracted from subsequent readings. After correction is performed, zero check returns to its previous state (enabled or disabled).

Programming Notes

1. Zero correction should be performed whenever the display is not zeroed when in zero check.
2. The specifications at the front of this manual assume that the instrument has been properly zeroed.

Programming Example

```
OUTPUT 722; "R1X"          ! Select 1nA range.
```

4.2.4 D — Display

Purpose

To display messages on the front panel.

Format

Da

Parameters

Da Display characters "a", where "a" represents printable ASCII characters.
D Return display to normal operation.

Default

Upon power-up, or after receiving a DCL or SDC command, the display returns to normal operation.

Description

The D command allows you to display messages on the front panel. Up to 18 characters, including blanks, can be sent by simply following the D command with ASCII characters. Characters that can be displayed include; 0-9, A-Z (except uppercase X), arithmetic and most punctuation symbols.

Programming Notes

1. Spaces in a message are displayed as blanks.
2. Sending a message that exceeds 18 characters will result with only the first 18 characters being displayed. The extra characters will be ignored.
3. For messages that are less than 18 character in length, the characters are left-hand justified and the rest of the display is blank.
4. Pressing LOCAL on the front panel will cancel the message and return the instrument to the normal display state.

Programming Examples

```
OUTPUT 722; "D MODEL 486X"    ! Display "MODEL 486".
OUTPUT 722; "DX"              ! Return display to normal.
```

4.2.5 F — V/I Ohms

Purpose

To control the V/I ohms function of the Model 487.

Format

Fn

Parameters

F0 Disable V/I ohms
F1 Enable V/I ohms

Default

Upon power-up or after receiving a DCL or SDC command, the instrument returns to the option of the F command that was saved as the default condition.

Description

For V/I ohms, resistance is automatically calculated (and displayed) from the applied voltage and the measured current in accordance with Ohms Law: R = V/I.

For complete information on using V/I ohms, refer to paragraph 3-7.

Programming Examples

```
OUTPUT 722; "F1X"          ! Enable V/I ohms.
OUTPUT 722; "F0X"          ! Disable V/I ohms.
```

4.2.6 G — Data Format

Purpose Control the format of output data that is transmitted over the bus.

Format **Gn**

Parameters

G0 ASCII readings with prefix
G1 ASCII readings without prefix
G2 ASCII readings and buffer location with prefix
G3 ASCII readings and buffer location without prefix
G4 Binary readings – IEEE Std 754 single-precision, bytes reversed for Intel CPUs.
G5 Binary readings – IEEE Std 754 single-precision, bytes in normal order for Motorola CPUs.
G6 Binary readings – counts and exponent, bytes reversed for Intel CPUs.
G7 Binary readings – counts and exponent, bytes in normal order for Motorola CPUs.

Default Upon power-up, or after receiving a DCL or SDC command, the instrument will return to the data format that was saved as the default condition.

Description Whenever the instrument is addressed to talk, it sends data over the IEEE-488 bus to the controller. The format of output data is determined by how it is configured with the G command. Figure 4-1 shows an example of an ASCII output data string that includes the buffer location and prefix.

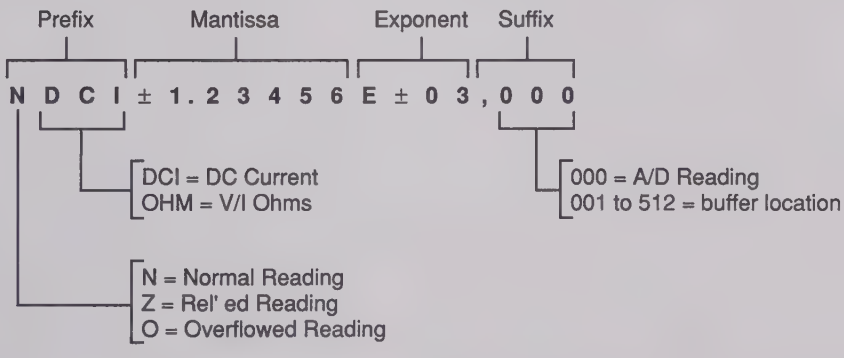
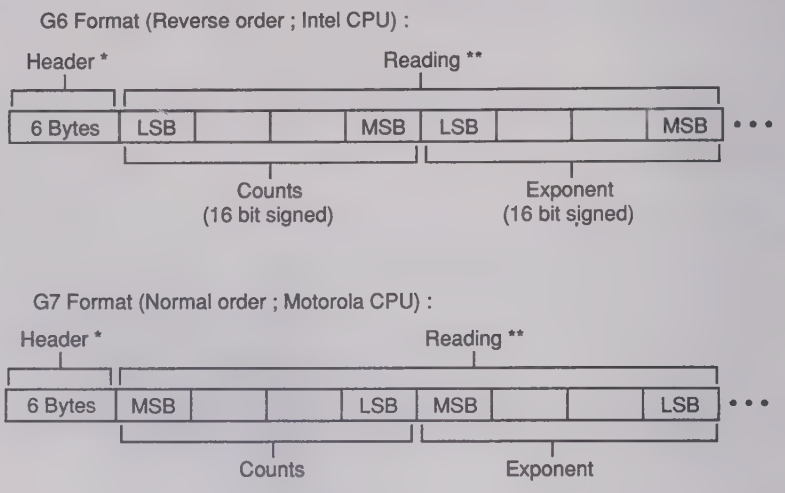

Prefix
Mantissa
Exponent
Suffix
N D C I ± 1 . 2 3 4 5 6 E ± 0 3 , 0 0 0
DCI = DC Current
OHM = V/I Ohms
000 = A/D Reading
001 to 512 = buffer location
N = Normal Reading
Z = Rel' ed Reading
O = Overflowed Reading

Figure 4-1. ASCII Data Format (G2; Prefix and Suffix)

The Model 486/487 can be programmed to output data in a binary format to Motorola or Intel CPUs. The binary data formats are shown in Figures 4-2 and 4-3. Note that the headers for these binary formats are shown in Figure 4-4.

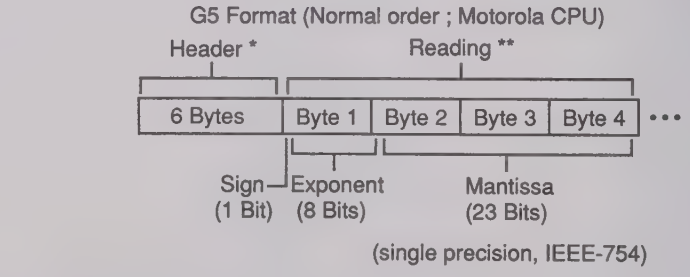


* Headers for the G6, and G7 formats are shown in Fig. 4-4

** When recalling data from the buffer, one header is followed by one or more readings, depending on buffer size.

NOTE : True reading = Counts X 10^{Exponent}

Figure 4-2. G6 and G7 Binary Data Formats (Counts/Exponent)



G4 Format (Reverse order ; Intel CPU) : Reading bytes sent in reverse order ; Header*, Byte 4, Byte 3, Byte 2, Byte 1

*Headers for the G4 and G5 formats are shown in Fig. 4-4

** When recalling data from the buffer, one header is followed by one or more readings, depending on buffer size.

Figure 4-3. G4 and G5 Binary Data Formats (IEEE Std. 754)

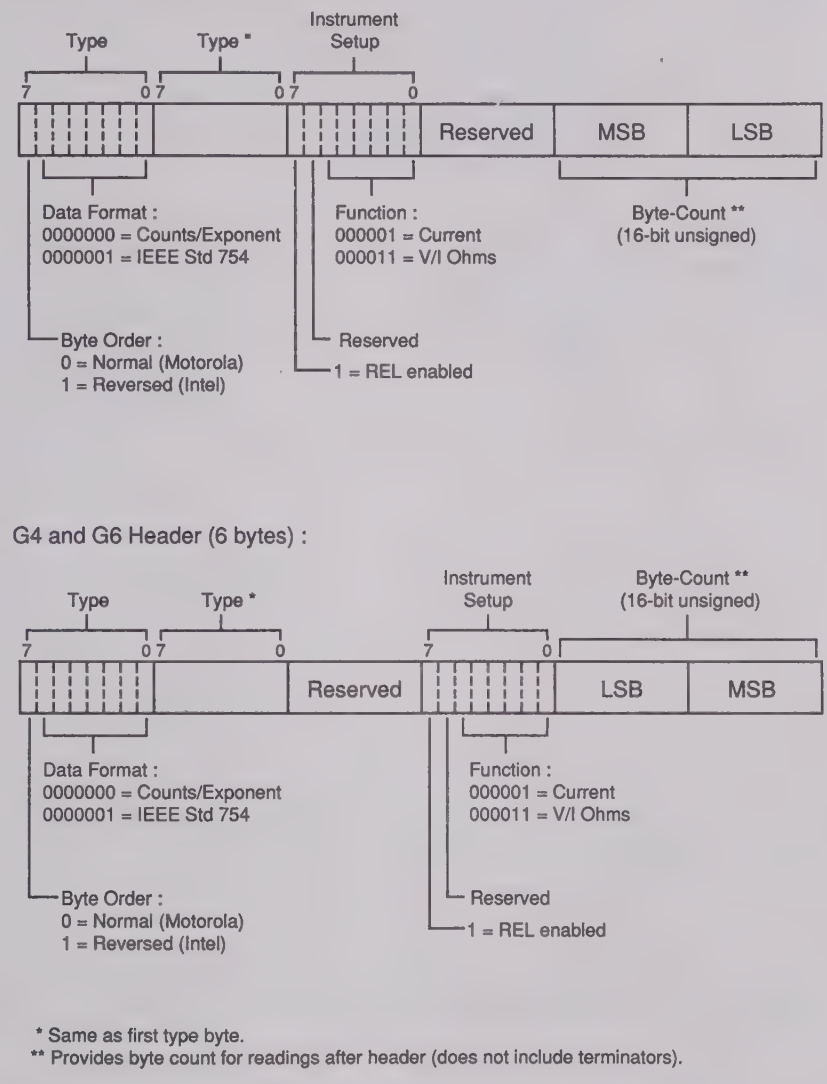


Figure 4-4. Headers For Binary Formats

The ASCII data format is in a direct readable form for the operator. Most BASIC languages will easily convert ASCII mantissa and exponent to other formats. However, some speed is compromised to accommodate the conversion.

The Count and Exponent format has some advantages over the ASCII format. It requires fewer bytes, transfers to the computer faster, and is compatible with most programming languages. This format is particularly useful when collecting data on a fixed range (autorange disabled).

The IEEE Standard 754 Single Precision format requires few bytes, and is used without conversion in popular personal computer programming languages.

Programming Notes

1. The B command affects the source of the data. In the B0 modes, the bus data will come from the A/D converter. In the B1 and B2 modes, the data will come from the buffer (data store).
2. Programmed terminator and EOI sequences appear at the end of each reading except in B2 which terminates only at the end of the string.
3. If a buffer location is not available, 000 is sent.
4. For an overflowed reading, ±9.87E37 appears in the data field.
5. For an infinite V/I Ohms reading, ±9.9E37 is used for formats G0-G3 and G6-G7. For G5 and G6 (IEEE Std, 754), the defined representation of infinity is used.

Programming Examples

```
10 REMOTE 722
20 OUTPUT 722; "B0G0X"        ! Program for A/D ASCII reading with prefix.
30 ENTER 722; A$              ! Send reading.
40 PRINT A$                   ! Display reading on CRT.
50 END
```

4.2.7 H — Hit Control

Purpose

Emulate front panel control actions.

Format

Hn

Parameters

H1 Hit DISPLAY INTENSITY key
H2 Hit LOCAL key
H3 Hit SHIFT key
H4 Hit MENU key
H5 Hit ZERO CHECK key
H6 Hit FILTER key
H7 Hit RANGE ▼ key
H8 Hit REL key
H9 Hit RANGE ▲ key
H10 Hit SETUP key
H11 Hit TRIGGER key
H12 Hit OPERATE key (Model 487)
H13 Hit PRESET key (Model 487)
H14 Hit ◀ key
H15 Hit ▶ key
H16 Hit Rotary Knob counterclockwise
H17 Hit Rotary Knob clockwise

Description

The hit command allows you to emulate virtually any front panel panel control sequence. The result of sending H1 through H15 is the same as physically pressing the appropriate front panel key. Sending H16 emulates turning the Rotary Knob one detent position counterclockwise. H17 is similar, but emulates turning the Rotary Knob one detent position clockwise.

Second functions of front panel keys are selected by first sending H3 (SHIFT). For example, to zero correct the instrument, send H3XH5X. This command string emulates pressing SHIFT and then ZERO CHECK.

Important consideration: To force a command sequence to emulate front panel actions, each H command must be terminated by an X. The previous example (H3XH5X; zero correction) demonstrates this. H3H5X is executed as H5X.

Programming Note

The H12 and H13 commands are invalid for the Model 486. Sending these commands to the Model 486 will result in an illegal device-dependent command option (IDDCO) error.

Programming Examples

```
OUTPUT 722; "H6X"          ! Hit FILTER key.
OUTPUT 722; "H3XH7X"       ! Hit SHIFT ▼ (autorange).
```

4.2.8 J — Self-Tests

Purpose

To perform self-tests on its memory elements and/or display.

Format

Jn

Parameters

J0 Perform ROM/RAM self-test
J1 Perform display and ROM/RAM self-tests

Description

Both J0 and J1 will perform tests on its memory elements (ROM and RAM). In the event of a failure, one or both of the following messages will be displayed:

ROM ERROR
RAM ERROR

The J1 command will also cause the display test to be run. For this test, each segment of all the LEDs will be sequentially displayed. Then, all segments of each LED will sequentially displayed. The display test takes approximately 17 seconds to complete.

The U0 and U1 status words can be examined to check for self-test errors.

Programming Example

```
OUTPUT 722; "J1X"          ! Perform display and memory tests.
```

4.2.9 K — EOI and Bus Hold-Off

Purpose

To enable/disable EOI and bus hold-off on X.

Format

Kn

Parameters

K0 Enable EOI; Enable bus hold-off on X
K1 Disable EOI; Enable bus hold-off on X
K2 Enable EOI; Disable bus hold-off on X
K3 Disable EOI; Disable bus hold-off on X

Default

Upon power-up, or after the instrument receives a DCL or SDC command, the instrument will return to the K option that was saved as the default condition.

Description

The EOI line provides one method to positively identify the last byte in the data string sent by the instrument. When enabled, EOI will be asserted with the last byte the instrument sends over the bus.

Bus hold-off allows the instrument to temporarily hold up bus operation via the NRFD line when it receives the X character until all commands are processed. Hold-off will ensure that all commands have been executed at the time the bus is released. The hold-off period depends on the commands being processed. Table 4-2 lists hold off times for a number of different commands.

Programming Notes

1. Some controllers rely on EOI to terminate their input sequences. Suppressing EOI may cause the controller input sequence to hang.
2. When enabled, EOI will be asserted with the last byte in the terminator (if enabled), or with the last byte in the data string if the terminator has been disabled.

Programming Examples

```
OUTPUT 722;"K1X"        ! Disable EOI; enable hold-off on X
OUTPUT 722;"K0X"        ! Enable EOI; enable hold-off on X
```

Table 4-2. Typical Bus Holdoff Times

Description	Command*	Time
Display Intensity	A1	6.477msec
Reading Source	B0	6.287msec
Zero Check	C0	684.2msec
Zero Correct	C2	1.257sec
Display Message	DK	6.815msec
	DKEITHLEY	8.028msec
V/I Ohms	F1	7.936msec
Output Format	G1	6.543msec
Selftest	J0	3.628sec
	J1	20.27sec
EOI and X Holdoff	K1	7.229msec
	K2	6.339msec
Default Factory	L0	1.544sec
	L1	250.7msec
	L2	1.346sec
("C0X")	L3,1E–9	27.05sec
Set Mask	M1	6.185msec
	M35	6.380msec
Set Buffer Size	N0	12.25msec
	N512	10.09msec
Operate	O1	17.95msec
Filter	P0	8.105msec
	P1, P2	8.704msec
Trigger Interval	Q0	6.845msec
	Q10E–3	8.279msec
Select Range	R4	12.06msec
	R10	7.419msec
Integration Period	S0	107.9msec
Trigger Source/Mode	T0	7.066msec
	T4, T5	42.11msec
Alternate Output	U1	6.257msec
Voltage Source Value	V500, 1, 1	27.69msec
("O1C0X")	V500, 1, 1	28.84msec
("O1C0X")	V50, 0, 1	25.75msec
Trigger Delay	W0	7.376msec
	W9.99E2	8.192msec
Execute	X	5.053msec
Terminator	Y0	6.031msec
	Y1, Y2, Y3, Y4	6.231msec
Set Relative Value	Z1	10.40msec
	Z2, 1E–9	14.11msec
	Z3	11.93msec

*Commands were executed from the factory default configuration. The trigger was set to one-shot on external ("T7").

4.2.10 L — Default Conditions or Calibration

Purpose Dual purpose command: Use to establish default conditions, or use to calibrate the instrument.

Format **Ln**

Parameters

L0 Return to factory default conditions and save (L1) as default conditions.
L1 Save present machine states as default conditions.
L2 Return instrument to the saved default conditions.
L3,v Calibrate present measurement range using value (v), where v = –2mA to +2mA.
L4 Calibrate zero on present voltage source range of the Model 487.
L5 Calibrate full scale on present voltage source range on Model 487
L6 Prepare for calibration on present voltage source range on Model 487

Description

Default Conditions:

The L0 command allows the user to return the instrument to the factory default conditions. Factory default conditions are set at the factory and are listed in Table 4-3. At the same time, the factory default conditions are saved and become the default conditions on subsequent power-ups or when an SDC or DCL is sent over the bus.

Table 4-3. Factory Default Conditions

Control/Feature	DDC Asserted	Default Condition
Display Intensity*	A0	Normal display intensity
Reading Source*	B0	Reading from A/D
Zero Check*	C1	Zero check enabled
V/I Ohms*	F0	V/I ohms disabled
Data Format*	G0	ASCII reading with prefix
EOI & Bus Hold-Off*	K0	EOI and bus hold-off enabled
SRQ*	M0	SRQ disabled
Data Store	—	Unarmed
Operate (487)	O0	Voltage source in standby
Filters*	P3	Digital and analog filter enabled
Range*	R0	Autorange enabled
Integration*	S1	Line cycle; 5-1/2d resolution
Trigger*	T6	Multiple on external trigger
Voltage Source (487)*	V0,0,1	0V level, 50V range and 2.5mA limit
Terminator*	Y0	CR LF
Relative*	Z0	Relative disabled

*Device-dependent command whose options can be saved as user saved default condition.

The L1 command is used to save the current machine states. The instrument will then power up to these default conditions. Also, an SDC or DCL command sent over the bus will return the instrument to the user saved default conditions.

Device-dependent commands whose options can be saved as user saved default conditions are denoted by an asterisk (*) in Table 4-3.

When the L2 command is received, the instrument will immediately return to the currently saved default conditions. This is equivalent to sending the SDC or DCL command.

Note that the currently selected IEEE-488 address and line frequency setting are not affected by the L command. The instrument will always power up to the last selected address and line frequency setting.

Calibration:

CAUTION: Only send calibration commands (L3, L4, L5 and L6) when actually calibrating the instrument. The complete procedure to calibrate the Model 486/487 over the IEEE-488 bus is contained in Section 7.

Programming Example

On the Model 486/487, enable FILTER and REL. Enter the following statement into the computer:

```
OUTPUT 722; "L2X"          ! Restore saved default conditions.
```

4.2.11 M — SRQ Mask and Serial Poll Byte Format

Purpose

To program which conditions will generate an SRQ (service request).

Format

Mn

Parameters

M0 Disable SRQ
M1 Reading Overflow
M2 Data Store Full
M4 Data Store Half Full
M8 Reading Done
M16 Ready
M32 Error
M128 Voltage Source Error

Default

Upon power-up, or after the instrument receives a DCL or SDC command, the instrument will return to the M option that was saved as the default condition.

Description

SRQ Mask — The Model 486/487 uses an internal mask to determine which conditions will cause an SRQ (service request) to be generated. Figure 4-5 shows the general format of this mask, which is made up of eight bits.

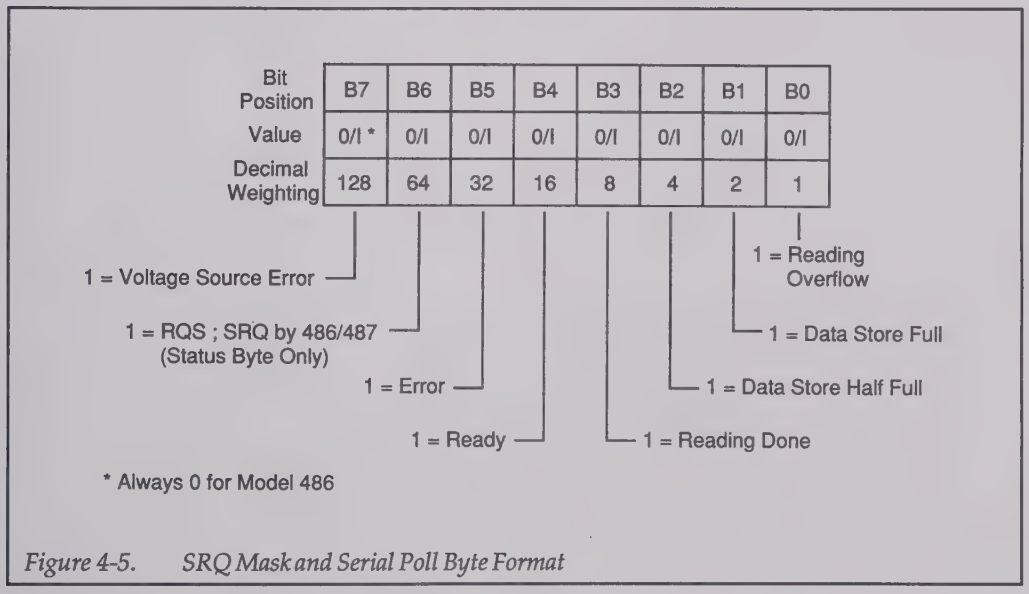


Figure 4-5. SRQ Mask and Serial Poll Byte Format

SRQ can be programmed by sending the ASCII letter "M" followed by a decimal number to set the appropriate bit in the SRQ mask. Decimal values for the various bits are included in Figure 4-5, and also listed in the "Parameters" section. Note that the instrument may be programmed for more than one set of conditions simultaneously. To do so, simply add up the decimal bit values for the required SRQ conditions. For example, to enable SRQ under reading overflow and buffer full conditions, send M3X. To disable SRQ, send M0X. This command will clear

Serial Poll Byte Format — The serial poll byte contains information relating to data and error conditions within the instrument. The general format of the status byte (which is obtained by using the serial polling sequence, as described in paragraph 4.3.7) is shown in Figure 4-5. Note that the various bits correspond to the bits in the SRQ mask as described above.

The bits in the serial poll byte have the following meanings:

Bit 0 (Reading Overflow) — Set when an overranged reading has been made. Cleared when an on-scale reading has been made.

Bit 1 (Data Store Full) — Set when the defined data store size is full. Cleared by re-arming the data store.

Bit 2 (Data Store 1/2 Full) — Set when half the defined data store size is full. Cleared by re-arming the data store.

Bit 3 (Reading Done) — Set when the instrument has completed the present reading conversion. Cleared after the instrument has sent a reading.

Bit 4 (Ready) — Set when the instrument has processed all previously received commands and is ready to accept additional commands or triggers. Cleared while the instrument is processing commands or triggers.

Bit 5 (Error) — Set when one of the following errors have occurred:

1. IDDC
2. IDDCO
3. No Remote
4. Selftest
5. Trigger Overrun
6. Conflict
7. Cal Locked
8. Zero Check
9. Calibration Error
10. E^2PROM Defaults Error
11. E^2PROM Cal Constants Error
12. V-Source Conflict (Model 487)
13. Interlock (Model 487)

This bit is cleared when the U1 status word is read to determine the type of error (see paragraph 4.2.19).

Bit 6 (RQS = Request for Service) — Set if the Model 486/487 asserted SRQ. Cleared when the instrument is serial polled.

Bit 7 (Voltage Source Error) — Set if the voltage source of the Model 487 becomes current limited or the interlock becomes unsafe. Cleared when the U9 status word is read after the voltage source errors are corrected. For the Model 486, this bit is always cleared (0).

Programming Notes

1. The serial poll byte should be read to clear the SRQ line once the instrument has generated an SRQ. All bits in the serial poll byte will be latched when the SRQ is generated. Bit 6 (RQS) will be cleared when the serial poll byte is read.
2. Even with SRQ disabled, the serial poll byte can be read to determine appropriate instrument conditions.

Programming Example

```
10  OUTPUT 722;"M32X"                ! Program for SRQ on error.
20  OUTPUT 722;"E1X"                 ! Attempt to program illegal command (IDDC).
30  IF NOT BIT (S,5) THEN 20         ! Wait for SRQ to occur.
40  S=SPOLL(722)                     ! Serial poll the 486/487.
50  DISP "B7 B6 B5 B4 B3 B2 B1 B0"   ! Label the bit positions.
60  FOR I=7 TO 0 STEP -1             ! Loop eight times.
70  DISP BIT(S,I);                   ! Display the bit positions.
80  NEXT I
90  DISP
100 END
```

4.2.12 N — Data Store; Arm and Set Size

Purpose

To arm, and set the buffer size of the data store.

Format

Nn

Parameters

N0 Set data store buffer for wrap around (endless) operation.
Nn Set data store buffer size "n" where "n" = 1 to 512.

Default

Upon power-up, or after receiving a DCL or SDC command, the instrument returns to the N option that was saved as the default condition.

Description

When the N command is sent over the bus, the data store becomes armed and starts storing readings when the appropriate trigger occurs. The rate that readings are stored is determined by the Q command (see paragraph 4.2.15).

In the wrap around data storage mode (N0), storage will not stop after the buffer is filled (512 readings), but will proceed back to the first buffer location and start overwriting data. With the Nn command, the storage process will stop when the defined number of readings have been stored. In this case, the buffer is considered to be full.

To store readings at a selected interval (Qn), the instrument must be in a multiple trigger mode (T0, T2, T4, T6 or T8). When the selected trigger occurs, the storage process will commence.

In a one-shot trigger mode (T1, T3, T5, T7 or T9), the instrument will store one reading each time the appropriate trigger occurs. See paragraph 4.2.18 for details on trigger commands.

Programming Notes

1. When the N command is sent, "------*" will be displayed until the first trigger occurs.
2. Data storage can be stopped by sending any one of the following commands: C, F, L, N, O, P, Q, R, S, T, V, W, Z or H if it simulates the actions of one of the other commands.
3. Either during or after the storage process, readings may be recalled by using the B1, B2, B3 or B4 command. In wrap-around buffer mode, data store must be stopped before readings may be taken from the buffer. Attempting to read the buffer while wrap-around data store is in progress will hang the bus.

Programming Examples

This program will enable data store operation, and obtain and display 100 readings on the computer CRT. Data store operation is configured as follows; continuous trigger on GET (T2) to start the storage process, 300msec interval (Q0.3) and a buffer size of 100 readings (N100).

```
10  DIM A$ [25]
20  REMOTE 722
30  OUTPUT 722; "T2Q0.3X"      ! Set trigger mode and interval.
40  OUTPUT 722; "N100X"        ! Set buffer size.
50  TRIGGER 722                ! Start storage process.
60  OUTPUT 722; "B1G2X"        ! Set data source and output.
70  FOR I=1 TO 100             ! Set counter for 100 loops.
80  ENTER 722; A$              ! Get a reading.
90  PRINT A$                   ! Display reading.
100 NEXT I                     ! Loop back for next reading.
110 END
```

4.2.13 O — Operate (Model 487)

Purpose

Use to place the voltage source of the Model 487 in operate.

Format

On

Parameters

O0 Place voltage source in standby.
O1 Place voltage source in operate.

Default

Upon power-up or after a DCL or SDC command is received over the bus, the voltage source will be placed in standby.

Description

In operate, the programmed voltage source level (V command) is available at the output of the Model 487. In standby, the voltage source is removed from the output.

Programming Note

When using Interlock, the unit cannot go into operate if the interlock switch is open (test fixture lid open).

Programming Examples

```
OUTPUT 722; "V1X"      ! Set source to 1V.
OUTPUT 722; "O1X"      ! Place Model 487 in operate.
OUTPUT 722; "O0X"      ! Place Model 487 in standby.
```

4.2.14 P — Filters

Purpose

Use to control the amount of filtering on the input signal.

Format

Pn

Parameters

P0 Digital and analog filters disabled.
P1 Digital filter enabled, analog filter disabled.
P2 Digital filter disabled, analog filter enabled.
P3 Digital and analog filters enabled.

Default

Upon power-up or after a DCL or SDC command is received over the bus, the instrument returns to the option of the P command that was saved as the default condition.

Description

In general, the Model 486/487 filters the input signal by taking the average of a number of successive reading samples. Since noise is mostly random in nature, it can be largely be canceled out by using one or both of these filters.

Paragraph 3.5.4 discusses the digital and analog filters in more detail.

Programming Examples

```
OUTPUT 722; "P3X"      ! Enable both filters.
OUTPUT 722; "P1X"      ! Enable digital filter, disable analog filter.
OUTPUT 722; "P0X"      ! Disable both filters.
```

4.2.15 Q — Interval

Purpose

Use to set the multiple trigger interval.

Format

Qn

Parameters

Q0 175msec factory default interval
Qn Set interval to "n" seconds where "n" = 0.010sec to 999.999sec.

Default

Upon power-up, or after receiving a DCL or SDC command, the instrument returns to the Q option that was saved as the default condition.

Description

Interval is used to control the storage rate of the data store. To store readings at a selected interval (Qn), the instrument must be in a multiple trigger mode (T0, T2, T4, T6 or T8). With the data store armed (see N command), the storage process will commence when the selected trigger occurs.

Although interval may be programmed to 0.010sec, readings will be made at intervals of no less than 0.050sec unless data store is in progress.

The programmed interval (Qn) also affects the interval between readings.

Programming Examples

```
OUTPUT 722; "Q1X"          ! Set interval to 1 second.
OUTPUT 722; "Q0X"          ! Set interval to 175msec.
```

4.2.16 R — Range

Purpose

Use the select the current measurement range.

Format

Rn

Parameters

R0	Enable autorange
R1	2nA range
R2	20nA range
R3	200nA range
R4	2µA range
R5	20µA range
R6	200µA range
R7	2mA range
R8	No range (IDDCO error)
R9	No range (IDDCO error)
R10	Disable autorange

Default

Upon power-up or after a DCL or SDC command is received over the bus, the instrument will return to the range parameter that was saved as the default condition.

Description

The range command gives the user control over the sensitivity of instrument measurements. This command, and its options, perform essentially the same functions as the front panel range buttons.

When autorange is enabled (R0) the instrument will go to the lowest possible range (without overranging) to make the measurement.

Commands R8 and R9 are invalid and will result in an IDDCO error if sent over the bus. Sending R10 will disable autorange. The instrument will stay on the present range.

Programming Example

```
OUTPUT 722; "R0X"        ! Enable autorange.
OUTPUT 722; "R10X"       ! Disable autorange.
```

4.2.17 S — Integration Period

Purpose Use to select the integration period and display resolution.

Format Sn

Parameters
S0 Fast integration period (4-1/2d resolution)
S1 Line cycle integration period (5-1/2d resolution)

Default Upon power-up or after a DCL or SDC command is received over the bus, the instrument will return to integration period that was saved as the default condition.

Description The integration command controls the integration period and the usable resolution of the Model 486/487. The fast integration period (S0) is 1.6msec with 4-1/2 digit display resolution.

The line cycle integration period depends on the selected frequency setting of the instrument, which is selected from the front panel MENU (see paragraph 3.8.4). With the instrument set for a line frequency of 50Hz, the line cycle integration period will be 20msec. For 60Hz, the line cycle integration period will be 16.67msec. Display resolution for line cycle integration is 5-1/2 digits.

Programming Note The line frequency setting (50 or 60Hz) cannot be performed over the bus. It can only be done from the front panel (see paragraph 3.8.4).

Programming Examples

```
OUTPUT 722; "S1X"      ! Select line cycle integration.
OUTPUT 722; "S0X"      ! Select fast integration.
```

4.2.18 T — Trigger

Purpose

Use to select the trigger mode and source.

Format

Tn

Parameters

T0 Multiple on Talk
T1 One-shot on Talk
T2 Multiple on GET
T3 One-shot on GET
T4 Multiple on X
T5 One-shot on X
T6 Multiple on External Trigger
T7 One-shot on External Trigger
T8 Multiple on Operate (Model 487)
T9 One-shot on Operate (Model 487)

Default

Upon power-up or after a DCL or SDC command is received over the bus, the instrument returns to the option of the T command that was saved as the default condition.

Description

Triggering provides a stimulus to begin a reading conversion within the instrument. Triggering may be done in two basic ways. In a multiple mode, a single trigger stimulus is used to start a continuous series of readings. In a one-shot trigger mode, a separate trigger stimulus is required to start each conversion.

The trigger modes are paired according to the type of stimulus that is used to trigger the instrument. In the T0 and T1 modes, a trigger stimulus is provided when the Model 486/487 is addressed to talk. In the T2 and T3 modes, the IEEE-488 multiline GET command performs the trigger function. In the T4 and T5 modes, the execute (X) character provides the trigger stimulus. In the T6 and T7 modes, external trigger pulses provide the trigger stimulus. In the T8 and T9 modes, placing the Model 487 in operate provides the trigger stimulus.

Sending T8 or T9 to the Model 486 will result in an IDDCO error.

Programming Examples

In the following example, the ENTER statement addresses the instrument to talk, at which point a single reading is triggered. When the reading has been processed, it is sent out over the bus to the computer, which then displays the result.

```
10 REMOTE 722
20 OUTPUT 722; "T1X"          ! One-shot trigger on talk.
30 ENTER 722; A$              ! Address 486/487 to talk.
40 PRINT A$                   ! Display one reading.
50 END
```

4.2.19 U — Status

Purpose Use to obtain instrument status and configuration.

Format **Un**

Parameters

U0 Send machine status word
U1 Send error status word
U2 Send model number and firmware revision
U3 Send calibration value
U4 Send trigger interval
U5 Send trigger delay
U6 Send relative value for current
U7 Send relative value for V/I ohms
U8 Send voltage source value (Model 487)
U9 Send voltage source error status word (Model 487)

Description

By sending the appropriate U command and then addressing the instrument to talk, you can obtain information on machine status, error conditions, and other data. The information is transmitted only once for each U command.

U0 Machine Status Word

When the command sequence U0X is transmitted, the instrument will transmit the status word instead of its normal data string the next time it is addressed to talk.

The format of U0 status is shown in Figure 4-6. Note that the letters correspond to modes programmed by the respective device-dependent commands. The factory default values are also shown in Figure 4-6.

Model 486: **486 A0 B0 C1 G0 H** J0 K0 M000 N000 P3 R11 S1 T6 Y0 Z0 c***

Model 487: **487 A0 B0 C1 F0 G0 H** J0 K0 M000 N000 O0 P3 R11 S1 T6 V01 Y0 Z0 c***

* Calibration switch (CAL LOCK) position; **Last pressed key

DISPLAY INTENSITY (A)
0 = Normal
1 = Dim
2 = Off

READING SOURCE (B)
0 = A/D Reading
1 = One data store reading
2 = All data store reading
3 = Max data store reading
4 = Min data store reading

ZERO CHECK and CORRECT (C)
0 = Zero check disabled
1 = Zero check enabled

V/I OHMS (F)
0 = V/I Ohms disabled
1 = V/I Ohms enabled

DATA FORMAT (G)
0 = Rdg with prefix (ASCII)
1 = Rdg without prefix(ASCII)
2 = Rdg and buffer location with prefix (ASCII)
3 = Rdg and buffer location without prefix (ASCII)
4 = Binary rdg – IEEE Std 754 single – precision, bytes reversed for Intel CPUs
5 = Binary Rdg – IEEE Std 754 single – precision, bytes in normal order for Motorola CPUs
6 = Binary Rdg – counts and exponent, bytes reversed for Intel CPUs
7 = Binary Rdg – Counts and exponent, bytes in normal order for Motorola CPUs

HIT CONTROL (H)
00 = POWER*
01 = DISPLAY INTENSITY*
02 = LOCAL*
03 = SHIFT*
04 = MENU*
05 = ZERO CHECK*
06 = FILTER*
07 = RANGE ▼*
08 = REL*
09 = RANGE ▲*
10 = SETUP*
11 = TRIGGER*
12 = OPERATE*
13 = PRESET*
14 = ◀*
15 = ▶*
16 = Knob rotated CCW
17 = Knob rotated CW
*Last pressed

SELF-TEST (J)
0 = No errors
1 = ROM error
2 = RAM error
3 = ROM and RAM error

EOI & BUS HOLD-OFF (K)
0 = EOI and Hold-off
1 = No EOI and Hold-off
2 = EOI and no Hold-off
3 = No EOI and no Hold-off

SRQ (M)
000 = Disabled
001 = Reading overflow
002 = Data Store Full
004 = Data Store 1/2 Full
008 = Reading Done
016 = Ready
032 = Error
128 = Voltage Source Error

DATA STORE SIZE (N)
000 = Wrap Around
nnn = 001 to 512

OPERATE (O)
0 = V-Source in Standby
1 = V-Source in Operate

FILTERS (P)
0 = Both Filters Disabled
1 = Digital Filter Enabled, Analog Filter Diabled
2 = Digital Filter Disabled Analog Filter Enabled
3 = Both Filters Enabled

RANGE (Rmn)
m: 0 = Autorange Disabled
1 = Autorange Enabled
n: 1 = 2nA range
2 = 20nA range
3 = 200nA range
4 = 2µA range
5 = 20µA range
6 = 200µA range
7 = 2mA

INTEGRATION PERIOD (S)
0 = Fast (4-1/2d)
1 = Line cycle (5-1/2d)

TRIGGER (T)
0 = Multiple on Talk
1 = One-shot on Talk
2 = Multiple on GET
3 = One-shot onm GET
4 = Multiple on X
5 = One-shot on X
6 = Multiple on External Trigger
7 = One-shot on External Trigger
8 = Multiple on Operate
9 = One-shot on Operate

VOLTAGE SOURCE (Vmn)
m: 0 = 50V range
1 = 500V range
n: 0 = 25µA Limit
1 = 25mA Limit

TERMINATOR (Y)
0 = CR LF
1 = LL CR
2 = CR
3 = LF
4 = None

RELATIVE (Z)
0 = Rel Disabled
1 = Rel Enabled

CAL LOCK (c)
0 = Switch in disabled (locked) position
1 = Switch in enable (locked) position

Figure 4-6 U0 Machine Status Word (Factory Defaults Shown)

U1 Error Status Word

The U1 command allows access to instrument error conditions in a similar manner. Once the sequence U1X is sent, the instrument will transmit the error conditions in the format shown in Figure 4-7 the next time it is addressed to talk.

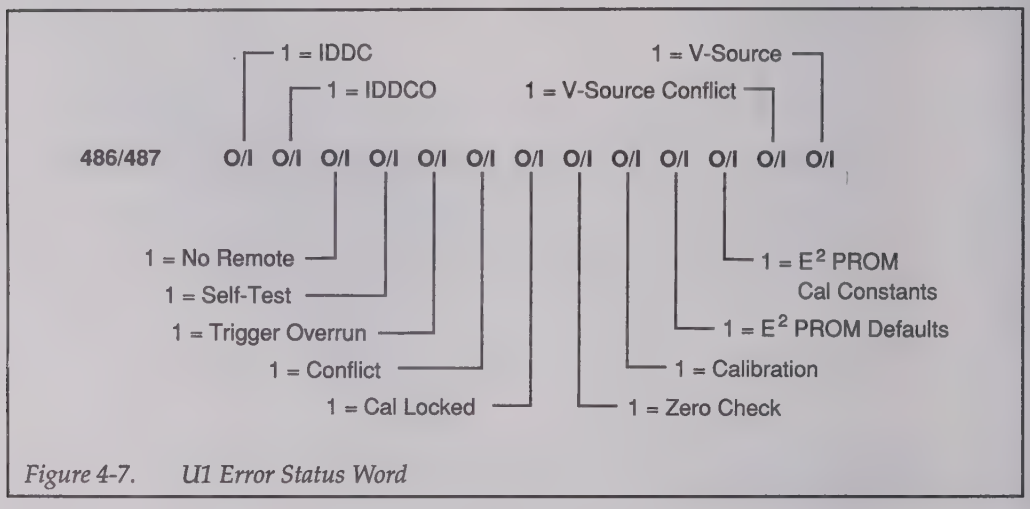

1 = IDDC
1 = IDDCO
1 = V-Source
1 = V-Source Conflict
486/487
O/I O/I O/I O/I O/I O/I O/I O/I O/I O/I O/I O/I O/I
1 = No Remote
1 = Self-Test
1 = Trigger Overrun
1 = Conflict
1 = Cal Locked
1 = Zero Check
1 = Calibration
1 = E2 PROM Defaults
1 = E2 PROM Cal Constants

Figure 4-7. U1 Error Status Word

The error status word is a string of ASCII characters representing binary bit positions. An error condition is also flagged by the serial poll byte, and the instrument can be programmed to generate an SRQ when an error occurs (see paragraph 4.2.11). Note that all bits in the error status word and the serial poll byte error bit will be cleared when the word is read. In addition, SRQ operation will be restored after an error by reading U1. The various bits in the error status word are described as follows:

IDDC — Set when an illegal device-dependent command (IDDC), such as E1X is received ("E" is illegal).

IDDCO — Set when an illegal device-dependent command option (IDDCO) such as T10X is received ("10" is illegal).

NO REMOTE — Set when a programming command is received when instrument is in the Local state.

SELF-TEST — Set when a self-test failure (RAM and/or ROM) occurs.

TRIGGER OVERRUN — Set when the instrument receives a trigger while it is still processing a reading from a previous trigger.

CONFLICT — Set when trying to send a calibration value with the instrument on a measurement range that is too small to accommodate the value.

CAL LOCKED — Set when calibrating the instrument with the calibration switch in the locked (disabled) position.

ZERO CHECK — Set when trying to calibrate the instrument with zero check enabled.

CALIBRATION — Set when calibration results in a cal constant value that is not within allowable limits. Repeated failure may indicate that the Model 486/487 is defective. See service information in this manual.

E²PROM DEFAULTS — Set when power-up checksum test on defaults fail.

E²PROM CAL CONSTANTS — Set when power-up checksum test on cal constants fail.

V-SOURCE CONFLICT — Set when trying to send a voltage source value to the Model 487 that exceeds the maximum limit of the currently selected voltage source range. On the Model 486, this bit is always reset to "0".

V-SOURCE — On the Model 487, this bit is set when trying to place the voltage source in operate while the enabled interlock is open. On the Model 486, this bit is always reset to "0".

U2 Model Number and Firmware Revision

By sending the U2 command and addressing the instrument to talk, the instrument model number and software revision level can be obtained. For example, if the software revision level of a Model 486 is A03, the following ASCII string will be obtained using the U2 command:

486A03

Note: There are two trailing blanks in this response message.

U3 Calibration Value

By sending the U3 command and addressing the instrument to talk, the last calibration value sent can be obtained. For example, if no calibration value has been sent, the following ASCII string will be obtained using the U3 command:

CV=+0.00000E–05A

U4 Trigger Interval

By sending the U4 command and addressing the instrument to talk, the currently programmed trigger interval (Q) can be obtained. For example, if the currently programmed trigger interval is 1.236 seconds, the following ASCII string will be obtained using the U4 command:

TI=001.236E+00S

U5 Trigger Delay

By sending the U5 command and addressing the instrument to talk, the currently programmed trigger delay (W) can be obtained. For example, if the currently programmed trigger delay is two seconds, the following ASCII string will be obtained using the U5 command:

TD=002.000E+00S

U6 Relative Value (Current)

By sending the U6 command and addressing the instrument to talk, the stored relative baseline value (Z) for current measurements can be obtained. For example, if the relative value for current is 1mA, the following ASCII string will be obtained using the U6 command:

RV=+1.00000E–03A

U7 Relative Value (V/I Ohms)

By sending the U7 command and addressing the instrument to talk, the stored relative baseline value (Z) for V/I ohms measurements can be obtained. For example, if the relative value for V/I ohms is 100Ω, the following ASCII string will be obtained using the U7 command:

RV=+1.00000E+02OHM

Note: Sending U7 to a Model 486 causes an IDDCO error.

U8 Voltage Source Value

By sending the U8 command and addressing the instrument to talk, the programmed voltage source value for the Model 487 can be obtained. For example, if the voltage source of the Model 487 is programmed for +20V, one of the following ASCII strings (depending on range) will be obtained using the U8 command:

VS=+20.000E+00V (V-Source on 50V range)

or

VS=+020.00E+00V (V-Source on 500V range)

Note: Sending the U8 command to the Model 486 will result in an IDDCO error.

U9 Voltage Source Error Status

By sending the U9 command and addressing the instrument to talk, the error status of the voltage source of the Model 487 can be obtained. The error status word is shown in Figure 4-8.

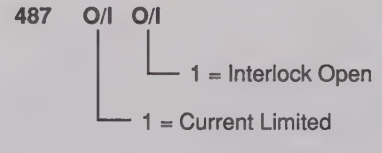


Figure 4-8. U9 Voltage Source Error Status Word

If the first bit of the word is set, the voltage source is now (or was previously) in current limit (25μA or 2.5mA). If the second bit of the word is set, the enabled interlock circuit is now (or was previously) open (i.e. lid of test fixture open).

Any set bits in this word will remain set until the U9 word is read by the controller. Of course, if the error(s) still exists, the bit(s) will not clear. Note that if any one of the two bits in the U9 status word becomes set, the voltage source error bit in the serial poll byte Error Status Word becomes set. The voltage source error bit in the serial poll byte word will not clear until all bits in the U9 word clear.

Note: Sending the U9 command to the Model 486 will result in an IDDCO error.

Programming Examples

The following program will obtain and display (on the computer CRT) the machine status word (U0):

```
10  REMOTE 722
20  DIM A$[60]
30  OUTPUT 722; "U0X"          ! Send U0 command.
40  ENTER 722; A$              ! Program 486/487 to talk.
50  PRINT A$                   ! Display U0 status word.
60  END
```

4.2.20 V — Voltage Source

Purpose

Use to program the voltage source value, range and current limit of the Model 487.

Format

Vn,r,l

Parameters

n – Specifies the voltage source level; –505V to +505V

r – Selects the voltage source range;

0 = 50V range
1 = 500V range

l – Specifies the current limit;

0 = 25µA limit
1 = 2.5mA limit

Default

Upon power-up or after a DCL or SDC command is received over the bus, the voltage source returns to the last saved default condition.

Description

The V command is used to program the voltage source of the Model 487. The voltage source level can be sent in normal decimal form (i.e. 236) or in exponential form (i.e. 2.36E+2).

All three parameters need not be sent with the V command. However, the commas that normally precede a parameter you are going to send must be included in the command string. The following examples are valid command strings:

Valid Command Strings:

V1X Sets source to 1V (range and limit not changed)
V,1X Selects 500V range (level and limit not changed)
V,,0X Selects 25µA current limit (level and range not changed)
V2,,1X Sets source to 2V and current limit to 2.5mA (range not changed)

Programming Notes

1. Sending a level value that exceeds ±505V will result in an IDDCO error. The entire command string will be ignored.
2. Sending a level value that exceeds the capability of the selected voltage source range will result in a CONFLICT error. The entire command string will be ignored.
3. Sending the V command to the Model 486 will result in an IDDC error.
4. The programmed voltage source will not be applied to the output until the instrument is placed in operate (O command).

Programming Example

```
OUTPUT 722; "V10,0,1X"        ! Program for 10V on the 50V range with a current limit of
                                2.5mA.
```

4.2.21 W — Delay

Purpose Use to set trigger delay time.

Format **Wn**

Parameters Wn Delay trigger by "n" seconds, where "n" = 0 to 999.999 seconds

Default Upon power-up or after a DCL or SDC command is received over the bus, the instrument returns to the trigger delay saved as the default condition.

Description The delay command controls the time interval that occurs from the point the instrument is triggered until it begins integration of the input signal. This feature is useful in situations where a specific time period must transpire to allow an input signal to settle before measurement.

Examples:

For a delay of 60sec, send W60X
For a delay of 2msec, send W.002X or W2E–3X (exponent form)

Programming Example

```
OUTPUT 722; "W250E–3X"          ! 250msec delay
```

4.2.22 X — Execute

Purpose

To direct the instrument to execute device-dependent commands received since the last X.

Format

<command> X

Parameters

None

Description

The execute command is implemented by sending an ASCII "X" over the bus. Its purpose is to direct the instrument to execute other device-dependent commands. Usually the execute character (X) is the last byte in the command string (a number of commands may be grouped together into one string). However, there may certain cases when it is desirable to send a command string at one time, and then send the execute character later on.

Programming Notes

1. Commands or command strings sent without the X character are not executed at that time, but they are stored in an internal command buffer for later execution. When the X is finally transmitted, the stored commands are executed, assuming that all commands in the previous string were valid.
2. Commands in an X-terminated string are executed in the following order:
   A. All commands, except H and L (default options), are executed simultaneously.
   B. A default option of the L command is executed next. A restore operation (L0 or L2) will return the instrument to a default state after executing the other commands. Thus, in effect, the other commands in the string are nullified. The save option (L1) saves the instrument states after the other commands (except H) are executed.
   C. The H command is the last command in the string to be executed.
3. To force a particular command sequence, include the X character after each command in the command string.
4. The X character can also be used to trigger, as described in paragraph 4.2.18.

Programming Examples

```
OUTPUT 722; "P1X"          ! Execute single command
OUTPUT 722; "P0O1X"        ! Execute multiple command string.
OUTPUT 722; "H3XH7X"       ! Force command sequence to enable (or disable)
                             autorange.
OUTPUT 722; "N0P1"         ! Send string without executing.
OUTPUT 722; "X"            ! Execute previous command string.
```

4.2.23 Y — Terminator

Purpose

To select the ASCII terminator sequence that marks the end of the instrument's data string or data word.

Format

Yn

Parameters

Y0 <CR><LF>
Y1 <LF><CR>
Y2 <CR>
Y3 <LF>
Y4 none

Default

Upon power-up or after a DCL or SDC command is received over the bus, the instrument will return to the terminator that was saved as the default condition.

Description

By using the Y command, you can program the number and type of terminator characters the instrument sends at the end of its data string. Available terminator characters are the commonly used CR (carriage return; ASCII 13), and LF (line feed; ASCII 10) characters. These terminators are recognized by most controllers. Selecting the wrong terminator for the controller could cause the bus to hang.

You also have the option of selecting that no terminators be sent (a common choice for binary output data format).

Programming Examples

```
OUTPUT 722; "Y1X"        ! Terminate on LF CR.
OUTPUT 722; "Y0X"        ! Restore factory default terminator.
```

4.2.24 Z — Relative

Purpose

Use to establish the displayed reading or an entered value as the baseline for subsequent measurements.

Format

Zn

Parameters

Z0 Disable relative
Z1 Enable relative; present reading becomes baseline value
Z2,v Enable relative using "v" as the baseline value where; v = –2mA to +2mA for current
v = 0Ω to 50.5E16Ω for V/I ohms
Z3 Enable relative using the baseline previously defined.

Default

Upon power-up or after a DCL or SDC command is received over the bus, the instrument will return to the option of the Z command that was saved as the default condition.

Description

In general, relative establishes a baseline value that is algebraically subtracted from the normal reading that reflects the actual input signal level. The difference of these two values is the actual reading. The details on relative are explained in paragraph 3.5.4. The following information will only cover the specifics concerning bus operation.

Sending the Z0 command disables relative but "remembers" the baseline value for possible future use (see Z3).

Sending the Z1 command is the same as enabling REL from the front panel. The present reading will become the baseline. All subsequent readings will then be the difference between the measured value and the baseline value.

Sending Z2,v enables relative and uses a baseline value that is defined by the "v" parameter. Examples of valid commands:

```
Z2,.001X        ! 1mA or 1mΩ baseline
Z2,1E–3X        ! 1mA or 1mΩ baseline (exponent form)
Z2,100X         ! 100 Ω baseline
```

Sending Z3 enables relative and uses the baseline that was previously established from the front panel, or the Z1 or Z2 commands.

Programming Notes

1. Autorange will not react to the relative baseline value. With autorange enabled, the instrument will go to the lowest measurement range that can accommodate the input signal. For example, if a 1mA baseline is used with the instrument on the 10µA range, the display will overrange. The instrument will not autorange to the 1mA range because it is seeing an input signal that belongs on the 10µA range.
2. Zero check and correct also do not react to the baseline value. For example, with relative

enabled, performing zero check and correct will result with the instrument displaying the result of zero minus the baseline level. Only the input signal is zero corrected; not the baseline.

3. Separate baseline values for current and V/I ohms are "remembered" by the instrument.

Programming Examples

```
OUTPUT 722; "Z3X          ! Enable relative using last established baseline.
OUTPUT 722; "Z0X          ! Disable relative.
```

4.3 GENERAL BUS COMMANDS

General bus commands are those commands such as DCL that have the same general meaning regardless of the instrument. Commands supported by the Model 486/487 are listed in Table 4-4 which also lists BASIC statements necessary to send each command. Note that commands requiring that a primary address be specified assume that the primary address is set to 22. This is the address that is set at the factory.

Table 4-4. IEEE Contact Designations

Contact Number	IEEE-488 Designation	Type
1	DIO1	Data
2	DIO2	Data
3	DIO3	Data
4	DIO4	Data
5	EOI (24)*	Management
6	DAV	Handshake
7	NRFD	Handshake
8	NDAC	Handshake
9	IFC	Management
10	SRQ	Management
11	ATN	Management
12	SHIELD	Ground
13	DIO5	Data
14	DIO6	Data
15	DIO7	Data
16	DIO8	Data
17	REN (24)*	Management
18	Gnd, (6)*	Ground
19	Gnd, (7)*	Ground
20	Gnd, (8)*	Ground
21	Gnd, (9)*	Ground
22	Gnd, (10)*	Ground
23	Gnd, (11)*	Ground
24	Gnd, LOGIC	Ground

*Numbers in parentheses refer to signal ground return of referenced contact number. EOI and REN signal lines return on contact 24.

4.3.1 REN (Remote Enable)

The remote enable command is sent to the Model 486/487 by the controller to set up the instrument for remote operation. Generally, the instrument should be placed in the remote mode before you attempt to program it over the bus. Simply setting REN true does not actually place the instrument in the remote state. Instead the instrument must be addressed to listen after setting REN true before it goes into remote.

Note that the instrument need not be in remote to be a talker.

Programming Example — This sequence is automatically performed by the controller when the following is typed into the keyboard.

```
REMOTE 722
```

After the RETURN key is pressed, the instrument is in the remote state, as indicated by the REM indicator. If not, check to see that the instrument is set to the proper primary address 22, and check to see that the bus connections are properly made.

Note that all front panel controls except for LOCAL (and, of course, POWER) are inoperative while the instrument is in remote. You can restore normal front panel operation by pressing the LOCAL key.

4.3.2 IFC (Interface Clear)

The IFC command is sent by the controller to place the Model 486/487 in the talker and listener idle states. The unit responds to the IFC command by canceling front panel TALK or LISTEN lights, if the instrument was previously placed in one of those states.

To send the IFC command, the controller need only set the IFC line true for a minimum of 100µsec.

Programming Example — Before demonstrating the IFC command, turn on the TALK indicator with the following statement:

```
ENTER 722; A$
```

At this point, the TALK light should be on. The IFC command can be sent by entering the following statement into the computer:

```
ABORTIO 7
```

After the RETURN key is pressed, the TALK indicator turns off, indicating that the instrument has gone into the talker idle state.

4.3.3 LLO (Local Lockout)

The LLO command is used to prevent local operation of the instrument. After the unit (which is in remote) receives LLO, all its front panel controls except POWER are inoperative. In this state, pressing LOCAL will not restore control to the front panel.

Programming Example — The LLO command is sent by entering the following statements:

```
REMOTE 722
LOCAL LOCKOUT 7
```

After the second statement is executed, the instrument's front panel controls are locked out, including the LOCAL key.

LLO remains in effect until REN is set false. To restore front panel operation after asserting LLO, as in the following example, enter:

```
LOCAL 7
```

4.3.4 GTL (Go To Local) and Local

The GTL command is used to take the instrument out of the remote state. Operation of the front panel keys will also be restored by GTL even if LLO is in effect. To cancel LLO, you must set REN false.

Programming Example — Place the instrument in the remote state with the following statement:

```
REMOTE 722
```

Now send GTL with the following statement:

```
LOCAL 722
```

Note that the instrument goes into the local state, and that operation of the front panel keys has now been restored.

4.3.5 DCL (Device Clear)

The DCL command may be used to clear the Model 486/487 and return it to its saved default conditions. Note that the DCL command is not an addressed command, so all instruments equipped to implement DCL will do so simultaneously. When the Model 486/487 receives a DCL command, it returns to the saved default conditions.

Programming Example — Place the unit in an operating mode that is not a saved default condition. Now enter the following statement from the controller keyboard:

```
CLEAR 7
```

When the RETURN key is pressed, the instrument returns to the saved default conditions.

4.3.6 SDC (Selective Device Clear)

The SDC command is an addressed command that performs essentially the same function as the DCL command. However, since each device must be individually addressed, the SDC command provides a method to clear only selected instruments instead of clearing all instruments simultaneously, as is the case with DCL. When the Model 486/487 receives the SDC command, it returns to the saved default conditions.

Programming Example — Place the unit in an operating mode that is not a saved default condition. Now enter the following statement from the controller keyboard:

```
CLEAR 722
```

This sends the following IEEE-488 commands: UNT UNL LISTEN 22 SDC. When the statement is executed, the instrument returns to the saved default configuration.

4.3.7 GET (Group Execute Trigger)

GET may be used to initiate a Model 486/487 trigger if the instrument is placed in the appropriate trigger mode. Information on triggering is located in paragraph 4.2.18.

Programming Example — Type in the following statements to place the instrument in the one-shot GET trigger mode.

```
REMOTE 722
OUTPUT 722;"T3X"
```

Now trigger a reading by sending GET with the following statement:

```
TRIGGER 722
```

This sends IEEE-488 commands UNT UNL LISTEN 22 GET. When the RETURN key is pressed, a reading conversion occurs. (The command TRIGGER 7 just sends GET. All listeners are triggered when the RETURN key is pressed.)

4.3.8 SPE, SPD (Serial Polling)

The serial polling sequence is used to obtain the Model 486/487 serial poll byte. The serial poll byte contains important information about internal functions, as described in paragraph 4.2.11. Generally, the serial polling sequence is used by the controller to determine which of several instruments has requested service with the SRQ line. However, the serial polling sequence may be performed at any time to obtain the status byte from the Model 486/487.

Programming Example — The SPOLL statement automatically performs the serial poll sequence. To demonstrate serial polling, enter in the following statements into the computer:

```
S=SPOLL (722)
PRINT "SPOLL BYTE =";S
```

After the first statement, the controller conducts the serial polling sequence, After the second statement is executed, the decimal value of the serial poll byte is displayed on the controller CRT.

4.4 IEEE-488 BUS CONNECTIONS

The Model 486/487 is intended to be connected to the IEEE-488 Bus through a cable equipped with standard IEEE-488 connectors, an example of which is shown in Figure 4-9 The connector is intended to be stacked to allow a number parallel connections at one instrument. Two screws are located on each connector to ensure that connections remain secure. Current standards call for metric threads, which are identified with dark colored screws. Earlier versions had different screws, which were silver colored. Do not attempt to use these type of connectors on the instrument, which is designed for metric threads.

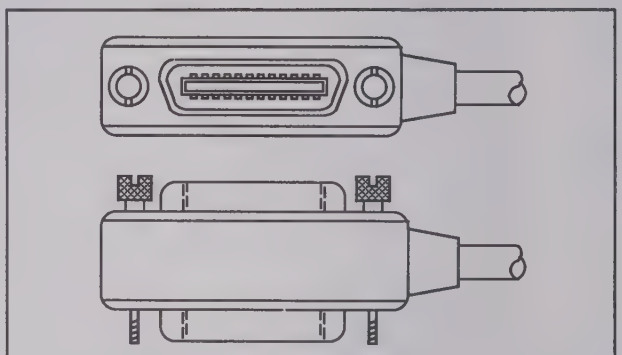


Figure 4-9. IEEE-488 Connector

A typical connecting scheme for a multi-unit test system is shown in Figure 4-10. Although any number of connectors could theoretically be stacked on one instrument, it is recommended that you stack no more than three connectors on any one unit to avoid possible mechanical damage.

NOTE
In order to minimize interference caused by electromagnetic radiation, it is recommended that only shielded IEEE-488 cables be used. The Models 7007-1 and 7007-2 shielded IEEE-488 cables are available from Keithley.

Connect the Model 486/487 to the IEEE-488 Bus as follows:

1. Line up the cable connector with the connector located on the rear panel of the Source Measure Unit. The connector is designed so that it will fit only one way. Figure 4-11 shows the location of the IEEE-488 connector on the instrument.
2. Tighten the screws securely, but do not overtighten them.
3. Add additional connectors from other instruments, as required.

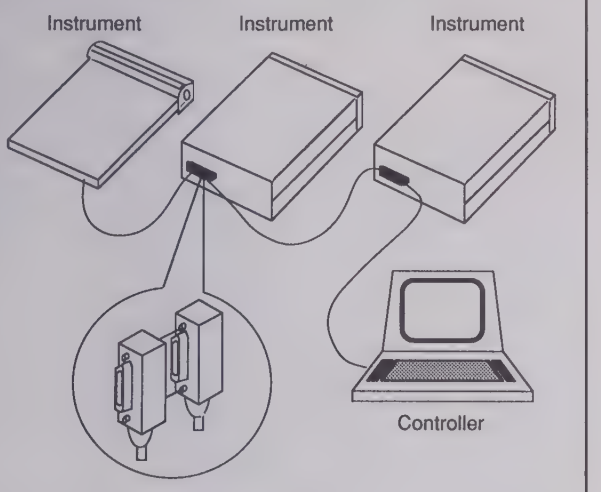


Figure 4-10. IEEE Connections

4. Make certain that the other end of the cable is properly connected to the controller. Most controllers are equipped with an IEEE-488 style connector, but a few may require a different type of connecting cable. Consult the instruction manual for your controller for the proper connecting method.

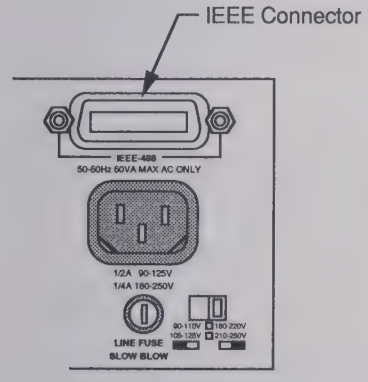


Figure 4-11. IEEE-488 Connector Location

NOTE

The IEEE-488 Bus is limited to a maximum of 15 devices, including the controller. The maximum cable length is 20-meters, or two meters times the number of devices, whichever is less. Failure to observe these limits may result in erratic bus operation.

Custom cables may be constructed by using the information in Table 4-4 and Figure 4-12. Table 4-4 lists the contact assignments for the bus, and Figure 4-12 shows the contact configuration.

CAUTION

IEEE-488 common is connected to digital common. Maximum voltage between digital common and earth ground is 30V.

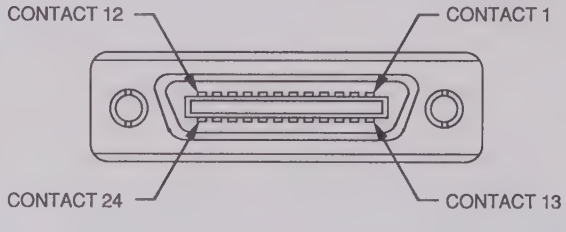


Figure 4-12. Contact Assignments

4.5 PRIMARY ADDRESS SELECTION

The Model 486/487 must receive a listen command before responding to addressed commands. Similarly, the unit must receive a talk command before transmitting data. The Model 486/487 is shipped from the factory with a programmed primary address of 22.

The primary address may be set to any value between 0 and 30 as long as address conflicts with other instruments are avoided. Note that controllers are also given a primary address, so do not use that address either. Most frequently, controller addresses are 0 or 21, but you should consult the controller's instruction manual for details. Whatever primary address you choose, you must make certain that it corresponds with the value specified as part of the controller's programming language.

To check the present primary address or to change to a new one, perform the following procedure:

1. Press the MENU button repeatedly until the primary address is displayed. For example, if the instrument is set to primary address 22, the following message will be displayed:

   IEEE-488 ADDR 22

2. To retain the displayed address, press SHIFT and then MENU to exit from the menu.

3. To change the primary address, use the rotary knob or the ADJUST (◀▶) to display the desired address.
4. To store the new address in memory, press MENU. The next menu selection (defaults) will be displayed.
5. Exit from the menu by pressing SHIFT and then MENU.

NOTE
Each device on the bus must have a unique primary address. Failure to observe this precaution will probably result in erratic bus operation.

4.6 CONTROLLER PROGRAMMING

The programming instructions covered in this section use examples written with Hewlett Packard BASIC version 4.0. This language was chosen because of its versatility in controlling the IEEE-488 bus. This section covers those statements that are essential to Model 486/487 operation.

NOTE
Controller programming information for using the IBM PC interfaced through the Capital Equipment Corporation (CEC), I/O Tech, and National IEEE-488 interfaces is located in Appendix D.

A partial list of HP BASIC 4.0 statements is shown in Table 4-5. The statements have a one or three digit argument that must be specified. The first digit is the interface select code, which is set to 7 at the factory. The last two digits of those statements requiring a 3-digit argument specify the primary address.

Those statements with a 3-digit argument show a primary address of 22 (the factory set primary address). For a different address, you would, of course, change the last two digits to the required value. For example, to send a GTL command to a device using a primary address of 17, the following statement would be used: LOCAL 717.

Some of the statements have two forms; the exact configuration depends on the command to be sent over the bus. For example, CLEAR 7 sends a DCL command, while CLEAR 722 sends the SDC command to a device with a primary address of 22.

Table 4-5. HP BASIC 4.0 IEEE-488 Statements

Action	BASIC Statement
Transmit string to device 22.	OUTPUT 722;A$
Obtain string from device 22.	ENTER 722;A$
Send GTL to device 22.	LOCAL 722
Send SDC to device 22.	CLEAR 722
Send DCL to all devices.	CLEAR 7
Send remote enable.	REMOTE 7
Cancel remote enable.	LOCAL 7
Serial poll device 22.	SPOLL (722)
Send local lockout. Send GTL to device 22.	LOCAL LOCKOUT 7 TRIGGER 722
Send IFC.	ABORT 7

4.7 FRONT PANEL ASPECTS OF IEEE-488 OPERATION

The following paragraphs discuss aspects of the front panel that are part of IEEE-488 operation, including messages, status indicators, and the LOCAL key.

4.7.1 Front Panel Error Messages

Table 4-6 summarizes the front panel error messages associated with IEEE-488 programming. Note that the instrument may be programmed to generate an SRQ, and U command status words can be checked for specific error conditions if any of these errors occur. See paragraphs 4.2.11 and 4.2.19.

The following paragraphs describe the front panel messages associated with IEEE-488 programming.

IDDC (Illegal Device-Dependent Command) Error

An IDDC error occurs when the unit receives an illegal device-dependent command over the bus. For example, the command string IX includes an illegal command because "I" is not part of the instrument's programming language. When an illegal command is received, the instrument briefly displays the IDDC error message.

NOTE
When an IDDC error is detected in a command string, all commands in the string, up to and including the next X, are ignored.

Table 4-6. IEEE-488 Error Messages

Message	Description
NO DEFLTS	Checksum error in default conditions during power-up.
UNCAL	Checksum error in calibration constants during power-up.
IDDC	Invalid device-dependent command.
IDDCO	Invalid device-dependent command option.
NO REMOTE	X received while not in remote.
ROM ERROR	Failed ROM self-test.
RAM ERROR	Failed RAM self-test.
TRG OVERUN	Trigger overrun; instrument triggered while still processing a previous trigger.
CONFLICT	Voltage source level of the Model 487 conflicts with currently selected voltage source range, or relative value conflicts with currently selected measurement range.
CAL VALUE	Calibration value conflicts with the currently selected range.
CAL LOCK	Sent calibration command with calibration switch (CAL LOCK) disabled.
CAL ERROR	Calibration value not within allowable limits.
CAL ZCHK	Cannot calibrate picoammeter with zero check enabled.

Programming Example — To demonstrate an IDDC error, use the following statements:

```
REMOTE 722
OUTPUT 722;"IX"
```

The IDDC error message is briefly displayed when the second statement above is executed.

IDDCO (Illegal Device-Dependent Command Option) Error

Sending the instrument a legal command with an illegal option results in the IDDCO error message being displayed. For example, the command P5X has an illegal option (5) that is not part of the instrument's programming language. Thus, although the command P is valid, the option is not, and the IDDCO error results.

NOTE

When an IDDCO error is detected in a command string, all commands in the string, up to and including the next X, are ignored.

Programming Example — Demonstrate an IDDCO error with the following statements:

```
REMOTE 722
OUTPUT 722;"P5X"
```

Note that the IDDCO error message is briefly displayed when the second statement above is executed.

No Remote Error

A not in remote error occurs if the instrument receives and "X" while it is in the local state. The NO REMOTE error message is displayed. This is caused by failing to set the REN line true before addressing the Model 486/487 to listen. (The HP9000 default is to set REN true.) The statement "REMOTE 7" sets the REN line true; the statement "REMOTE 722" sets the REN line true and addresses unit 22 to listen.

Programming Example — To demonstrate the NO REMOTE error message, type in the following lines:

```
LOCAL 7
OUTPUT 722;"F0X"
```

Note that the NO REMOTE error message is briefly displayed when the program times out.

Trigger Overrun Error

A trigger overrun occurs when the instrument is triggered while it is still processing a previous trigger and before the READY bit in the SPOLL byte is asserted. The exact trigger stimulus depends on the selected trigger mode, as discussed in paragraph 4.2.18.

The trigger stimulus that causes the trigger overrun is ignored but denoted in the U1 error status word and by the following message that is briefly displayed:

TRG OVERUN

Cal Value Error

A cal value error occurs when a calibration value sent over the bus (L command) exceeds the capabilities of the currently selected range. For example, sending a calibration value of 2mA on the 200µA range will cause a cal value error. The following message is briefly displayed when this error occurs:

CAL VALUE

Cal Error

A cal error indicates that calibration resulted in a cal constant value which is not within allowable limits. In the event of this error, the old cal constants are used. To clear the following displayed error messages, press any front panel key.

CAL ERROR

Cal Lock Error

When the CAL LOCK switch (accessed from the rear panel) is in the locked (out) position, calibration is disabled. Sending a calibration value (L command) over the bus will cause the following message to be briefly displayed:

CAL LOCK

The calibration command will be ignored.

Conflict Error

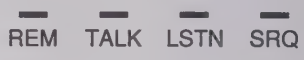
A conflict error pertains to the voltage source of the Model 487. This error occurs when trying to program the voltage source (using the V command) to a level that exceeds the limits of its selected range. When this error occurs, the following message is briefly displayed:

CONFLICT

The voltage source command is ignored.

4.7.2 IEEE-488 Status Indicators

The REM (remote), TALK (talk), LSTN (listen), and SRQ (service request) indicators show the present IEEE-488 status of the instrument. Each of these indicators is briefly described below.



REM — As the name implies, this indicator shows when the instrument is in the remote state. Note that REM does not necessarily indicate the state of the REN line, as the instrument must be addressed to listen with REN true before the REM indicator turns on. When the instrument is in remote, all front panel keys except for the LOCAL key are locked out. When REM is turned off, the instrument is in the local state, and front panel operation is restored.

TALK — This indicator is on when the instrument is in the talker active state. The unit is placed in this state by addressing it to talk with the correct MTA (My Talk Address) command. TALK is off when the unit is in the talker idle state. The instrument is placed in the talker idle state by sending it an UNT (Untalk) command, addressing it to listen, or with the IFC (Interface Clear) command.

LSTN — This indicator is on when the Model 486/487 is in the listener active state, which is activated by addressing the instrument to listen with the correct MLA (My Listen Address) command. Listen is off when the unit is in the listener idle state. The unit can be placed in the listener idle state by sending UNL (Unlisten), addressing it to talk, or by sending IFC (Interface Clear) over the bus.

SRQ — The instrument can be programmed to generate a service request (SRQ) when one or more errors or conditions occur. When this indicator is on, a service request has been generated. This indicator will stay on until the serial poll byte is read. See paragraph 4.2.11 for details.

4.7.3 LOCAL Key

The LOCAL key cancels the remote state and restores local operation of the instrument.

Since all front panel keys except LOCAL are locked out when the instrument is in remote, this key provides a convenient method of restoring front panel operation. Pressing LOCAL also turns off the REM indicator, and returns the display to normal if a message was displayed with the D command. (See paragraph 4.2.4).

Note that the LOCAL key is also inoperative if the LLO (Local Lockout) command is in effect.

4.8 BUS DATA TRANSMISSION TIMES

A primary consideration is the length of time it takes to obtain a reading once the instrument is triggered to make a conversion. The length of time will vary somewhat depending on the selected function and trigger mode. Table 4-7 gives typical times.

Table 4-7. Typical Trigger to First Byte Out Times

Setup	Integration	Typical Time (ms)
T1G5R1P3	FAST	25.72
T1G5R1P3	LINE60Hz	43.56
T1G5R1P3	LINE50Hz	42.65

T1 = One-shot on Talk
G5 = Binary rdgs: IEEE std 754 single-precision, bytes in normal order for Motorola CPUs.
R1 = 2nA range
P3 = Digital and Analog Filters enabled.

SECTION 5
Performance Verification

5.1 INTRODUCTION

The procedure outlined in this section may be used to verify that the instrument is operating within the limits stated in the specifications at the front of this manual. Performance verification may be performed when the instrument is first received to ensure that no damage or misadjustment has occurred during shipment. Verification may also be performed whenever there is question of instrument accuracy, or following calibration, if desired.

NOTE
If the instrument is still under warranty (less than 1 year from the date of shipment), and its performance falls outside the specified range, contact your Keithley representative or the factory to determine the correct course of action.

5.2 ENVIRONMENTAL CONDITIONS

All measurements should be made at 18-28°C (65-82°F) and at less than 70% humidity.

5.3 INITIAL CONDITIONS

The Model 486/487 must be turned on and allowed to warm up for at least two hours before beginning the verification procedures. If the instrument has been subject to extremes of temperature (outside the range specified in paragraph 5.2), additional time should be allowed for internal temperatures to reach normal operating temperature. Typically, it takes one additional hour to stabilize a unit that is 10°C (18°F) outside the specified temperature range.

5.4 REQUIRED TEST EQUIPMENT

Table 5-1 lists all the test equipment required for verification. The procedure for performance verification is based on using this exact equipment.

NOTE
The verification limits in this section do not include test equipment tolerance and are based on the one year accuracy specifications of the Model 486/487.

Alternate equipment may be used as long as the substitute equipment has specifications at least as good as those listed in Table 5-1.

Table 5-1. Verification Equipment

Item	Manufacturer	Model	Description	Specifications
A*	Keithley	263	Calibrator/Source (5-1/2 digits)	2nA, 20nA ranges; ±(0.065% + 10 counts) 200nA range; ±(0.035% + 10 counts) 2μA-2mA ranges; ±(0.025% + 10 counts)
B*	Keithley	6171	3-slot male to 2-lug female triax adapter	—
C*	Keithley	7024-3	2-slot triax cable	—
D**	Keithley	197	DMM (dc Volts) (5-1/2 digits)	200V, 1000V ranges; ±(0.015% + 2 counts)
E**	Pomona	B-24	Banana Plug Cable (2 required)	—

*Items A, B and C are used to verify the picoammeter of the Models 486 and 487.
**Items D and E are used to verify the voltage source of the Model 487.

5.5 VERIFICATION PROCEDURES

The following paragraphs contain the detailed procedures for verifying the one year accuracy specifications of the Model 486/487 using the equipment listed in Table 5-1. The allowable reading limits in these procedures do not include error that could be contributed by this equipment.

These procedures are intended for use only by qualified personnel using accurate and reliable test equipment. If the instrument is out of specifications and not under warranty, refer to the calibration information in this manual.

WARNING

The procedures to verify the voltage source of the Model 487 expose the user to dangerous voltages. Use standard safety precautions when such dangerous voltages are encountered.

5.5.1 Picoammeter Verification

Perform the following steps to verify the performance of the picoammeter of the Model 486/487:

1. Return the Model 486/487 to factory default conditions as follows:
   A. Press and release MENU until the following message is displayed:

      DEFAULTS OK

   B. Use the rotary knob to display the following message:

      DEFAULTS FACTORY

   C. Press MENU. The instrument will return to factory default conditions.
2. After factory initialization (Step 1), the instrument should be on the 2mA range with zero check enabled. Select the 2nA range and verify that the reading on the display is within the following limits:

   –0.00100nA to 0.00100nA

3. Perform zero correction by pressing SHIFT and then CORRECT. Verify that the reading on the display is zero ±50 counts (±50fA).
4. Using the RANGE▲ key, check that all the other current ranges display a reading of zero ±20 counts.
5. Connect the Model 263 current source to the Model 486/487 as shown in Figure 5-1. Configure the Model 263 for V/R AMPS, and make sure that GUARD is disabled and the ground link is installed.
6. Set the Model 486/487 to the 2nA range.
7. Set the Model 263 to the 2nA range and apply 1.90000nA to the Model 486/487.
8. On the Model 486/487, disable zero check and verify that the reading on its display is within the limits listed in Table 5-2 for the 2nA range.
9. On the Model 486/487, enable zero check and select the 20nA range.
10. Set the Model 263 to the 20nA range and apply 19.0000nA to the Model 486/487.
11. Disable zero check on the Model 486/487 and verify that the reading on its display is within the limits listed in Table 5-2 for the 20nA range.
12. Referring to Table 5-2, repeat the basic procedure of steps 9, 10, and 11 to check the 200nA through 2mA ranges of the Model 486/487.
13. Repeat the basic procedure of steps 6 through 12 for negative (–) current.

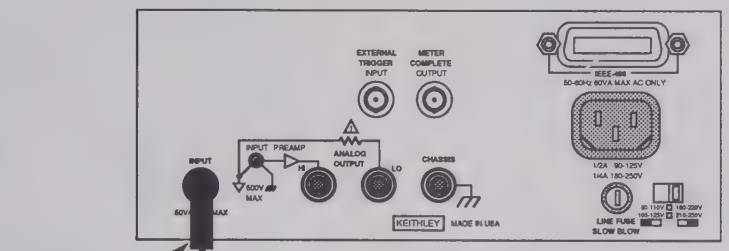


Figure 5-1. Setup for Picoammeter Verification

Table 5-2 Picoammeter Verification

486/487 Range	263 V/R AMPS Range	263 Current Setting	Allowable Reading* (18°C to 28°C)
2nA	2nA	1.90000nA	1.89380nA to 1.90620nA
20nA	20nA	19.0000nA	18.9590nA to 19.0410nA
200nA	200nA	190.000nA	189.695nA to 190.305nA
2µA	2µA	1.90000µA	1.89695µA to 1.90305µA
20µA	20µA	19.0000µA	18.9790µA to 19.0210µA
200µA	200µA	190.000µA	189.790µA to 190.210µA
2mA	2mA	1.90000mA	1.89790mA to 1.90210mA

*Based on accuracy specifications of Model 486/487. Does not include errors that may be contributed by the verification equipment.

5.5.2 Voltage Source Verification (Model 487)

Perform the following steps to verify the V-Source (voltage source) of the Model 487:

WARNING
The following procedure uses hazardous voltages that could cause severe injury or death. Exercise extreme caution when performing this procedure.

1. Make sure the V-Source of the Model 487 is in standby, then connect the Model 197 DMM to it as shown in Figure 5-2.
2. Set the Model 197 DMM to the 200mV range, and zero its display as follows:
   A. Temporarily disconnect the test leads at the Model 487 and short them together.
   B. Allow the reading on the Model 197 to settle.
   C. Press the REL button to zero the Model 197.
   D. Reconnect the test leads to the Model 487 as shown in Figure 5-2.
3. While in standby, set the V-Source level to 00.000V on the 50V range.
4. Place the V-Source in operate and verify that the reading on the Model 197 is within the following limit:

   –4.000mV to 4.000mV

5. Using the ◀ key, set the V-Source to 000.00V on the 500V range.
6. Verify that the reading on the Model 197 is within the following limit:

   –40.000mV to 40.000mV

7. Place the V-Source in standby.
8. Set the Model 197 DMM to the 200V range.
9. Set the V-Source level to 50.000V on the 50V range.
10. Place the V-Source in operate and verify that the reading on the Model 197 is within the following limits:

    49.946V to 50.054V

11. Place the V-Source in standby.
12. Set the Model 197 to the 1000V range.
13. Set the V-Source level to 500.00V.
14. Place the V-Source in operate and verify that the reading on the Model 197 is within the following limits:

    499.21V to 500.79V

15. Place the Model 487 in standby.
16. Repeat the basic procedure in steps 8 through 15, but set the V-Source for negative (–) voltages. The allowable readings will have a negative polarity.

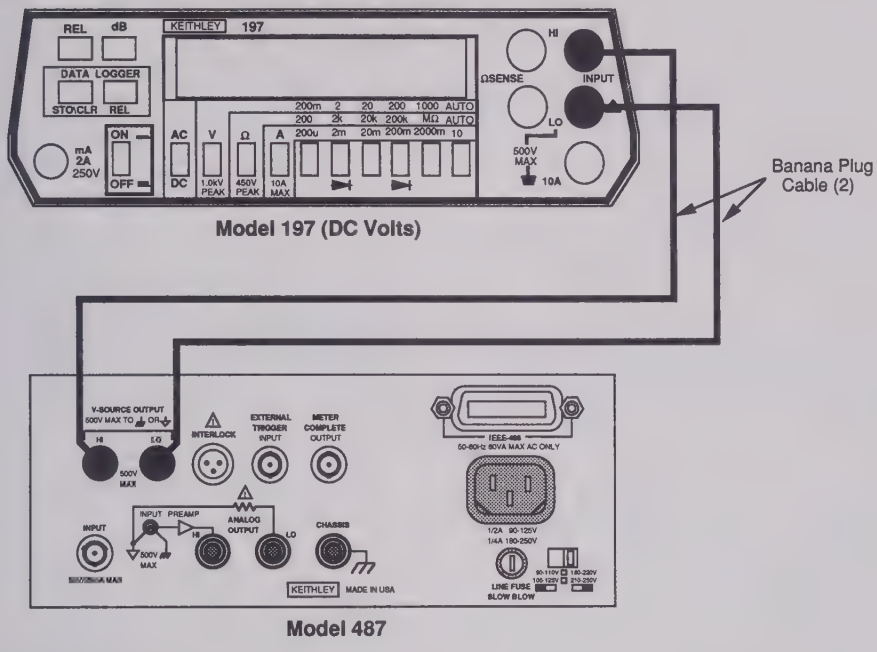


Figure 5-2. Setup for Voltage Source Verification (Model 487)

SECTION 6
Theory of Operation

6.1 INTRODUCTION

This section contains electronic operating theory for the various circuits within the Model 486/487. The overall block diagram of the instrument made up of these various circuits is shown in Figure 6-1.

6.2 ANALOG CIRCUITS

6.2.1 Input Amplifier

The input amplifier circuit for the instrument is found on page one of schematic drawing 486-106 or 487-106.

The current-to-voltage input amplifier of the Model 486/487 is designed around op amp U142 achieving low input bias current, low input offset voltage drift, and low input noise voltage.

The gain of the amplifier is selected by switching in the appropriate feedback resistor. Switching is provided by relays K104-K109. Table 6-1 identifies the relay(s) closed for each current range.

A simplified model of the input amplifier is shown in Figure 6-2. The input current is I_{IN}, while the current through the feedback resistor (R_F) is I_F. Since no current flows into the (–) terminal of the op-amp, $I_F = I_{IN}$. The negative feedback configuration and high gain op-amp make the input voltage equal to the input offset voltage (V_{OS}) of the op-amp. Thus,

$$V_{OUT} = -I_F R_F + V_{OS}$$
$$= -I_{IN} R_F + V_{OS}$$

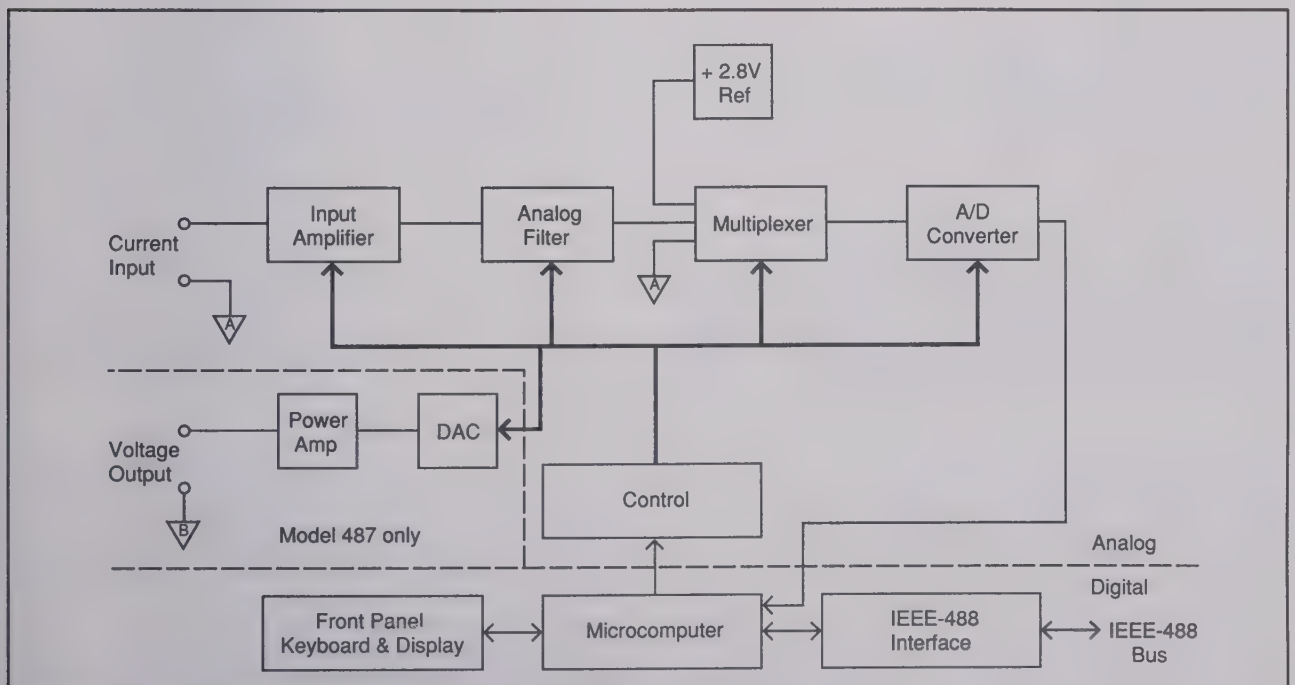


Figure 6-1. Overall Block Diagram

Table 6-1. Range Relays

Current Range	Range Relays Closed
2mA	K104, K105
200µA	K104, K106
20µA	K104
2µA	K107, K108
200nA	K107
20nA	K109
2nA	None

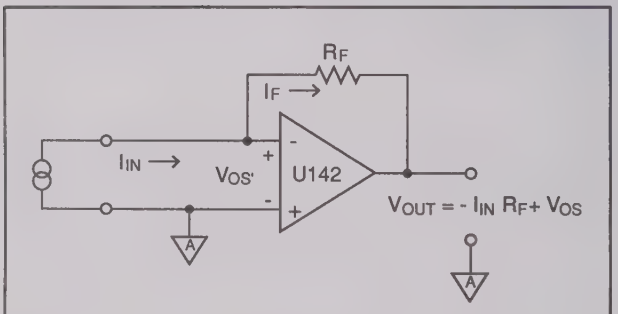


Figure 6-2. Simplified Model of Input Amplifier

For example, with the 2mA range selected, R_F = 1kΩ || 100kΩ. The output voltage with a 1mA input current is (V_{OS} ≈ 200µV):

$$V_{OUT} = -(1mA)(1k\Omega \,||100k\Omega) + 200\mu V$$
$$= -0.9898V$$

Zero Check

Figure 6-3 shows the configuration of the input amplifier with zero check enabled. With zero check enabled, relay switch K110 opens forcing the input current to common through R226 (100kΩ). With the input of U142 open, only amplifier offset is seen at the output (V_{OUT}).

With zero check disabled (relay switch K110 closed), the input current is simply applied to the (–) input of the amplifier as previously shown in Figure 6-2.

Offset Voltage Adjust

The previous simplified drawings of the input amplifier show the (+) input connected to common. Actually, a 10Ω resistor is located between the (+) input and common as shown in Figure 6-4. This allows a trimpot (R198) to be used as a coarse adjustment for input offset voltage. Any remaining offset is canceled when the operator performs zero correction from the front panel or over the bus.

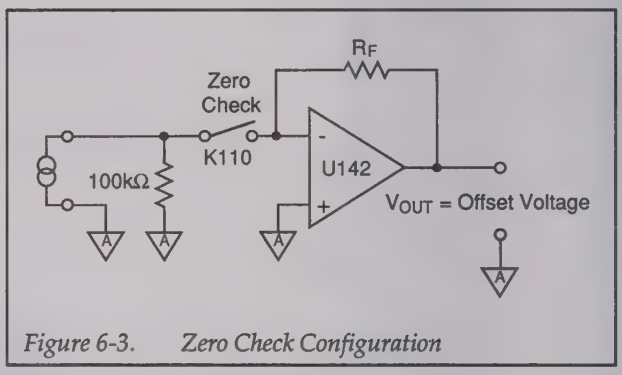


Figure 6-3. Zero Check Configuration

The offset voltage trimpot is set at the factory and should not be adjusted unless a component in that circuit is replaced. Refer to the troubleshooting information in paragraph 7.7 if it becomes necessary to adjust offset voltage.

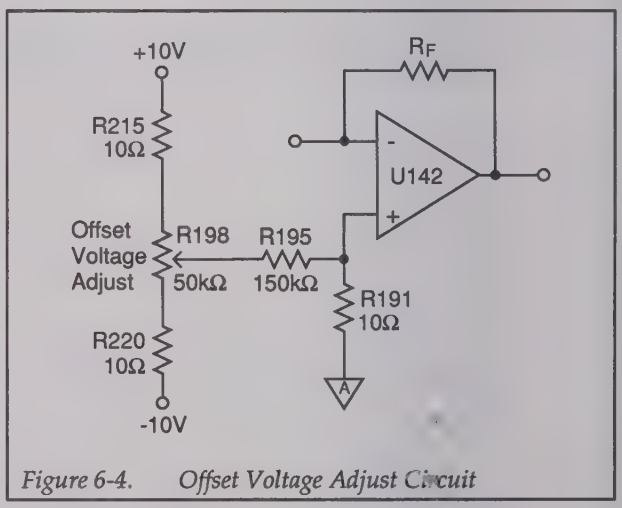


Figure 6-4. Offset Voltage Adjust Circuit

6.2.2 Analog Filter

The analog filter of the instrument is shown within the dashed lines of Figure 6-5. Filtering is provided by switching in various resistor/capacitor (RC) combinations. Switching is provided by analog switches A, B, C, D and E.

Table 6-2 identifies the configuration (open or closed) of each analog switch for all the current ranges. The analog

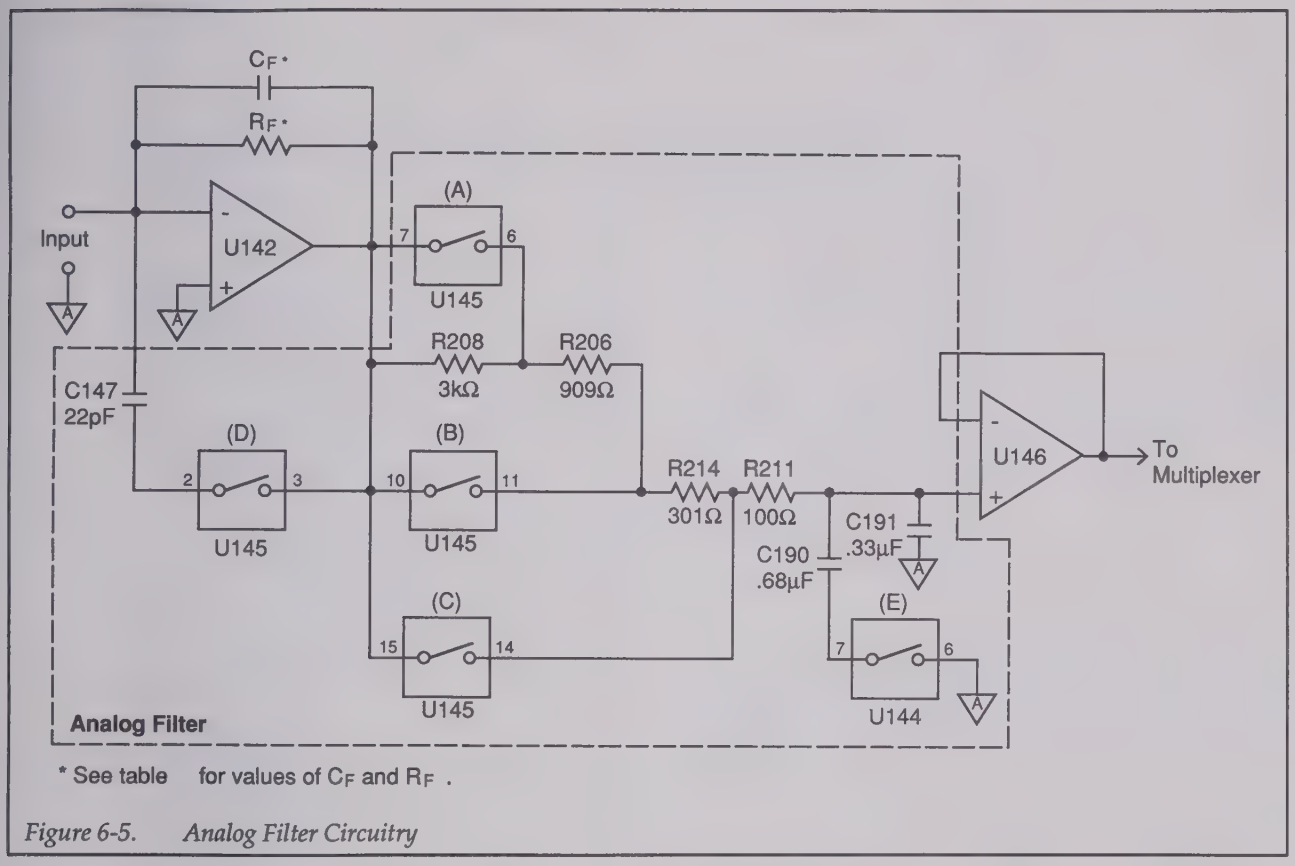


Figure 6-5. Analog Filter Circuitry

filter is enabled when the ANALOG or ANALOG+DIGITAL filter is selected and enabled (front panel FILTER indicator on). Table 3-6 in Section 3 of this manual lists the effects of the analog filter on rise time and settling time.

After filtering, the conditioned voltage signal is routed to the multiplexer via a x1 buffer (U146). The buffer isolates the input stage from the analog output circuitry.

6.2.3 Multiplexer

The multiplexer circuitry selects among the various signals that are part of the instrument measurement cycle and connects them to the A/D converter. The multiplexer circuit is shown in Figure 6-6. Device U132 is not part of the multiplexer but serves as a x1 buffer to isolate the A/D converter from the rest of the analog circuitry.

Figure 6-7 shows the general switching phases for the various signals. During each phase, an integration is performed by the A/D converter, and the resultant data is used by the microprocessor to calculate the final reading.

6.2.4 +2.8V Reference

Current measurements are based on comparing the unknown signal with an internal +2.8V reference. During each measurement cycle, the unknown signal is sampled and then compared with signal common and the +2.8V reference values.

The +2.8V reference is derived from a 6.4V reference source that is shown on sheet 2 of schematic 486-106 or 487-106. VR103 provides a highly stable 6.4V reference, while U114 and R147 provide a constant current to minimize zener voltage variations. R188 and R192 (on sheet 1 of the schematic) divide down the 6.4V value to the final +2.8V reference.

Table 6-2. Filter Relay Switching

Range	Analog Filter Enabled Filter Relay Switches*					Analog Filter Disabled Filter Relay Switches*				
	A	B	C	D	E	A	B	C	D	E**
2mA	O	O	C	C	C	O	O	C	O	O
200µA	O	O	C	C	C	O	O	C	O	O
20µA	O	O	C	C	C	O	O	C	O	O
2µA	O	C	O	C	C	O	O	C	O	O
200nA	C	O	O	C	C	O	C	O	O	C
20nA	O	O	O	C	C	O	C	O	O	C
2nA	O	O	O	C	C	C	O	O	O	C

C = Relay switch Closed
O = Relay Switch Open

*Relay switches A through E are shown in Figure 6-5.
**Zero check disabled. With zero check enabled, Relay E is closed (C) for all current ranges.

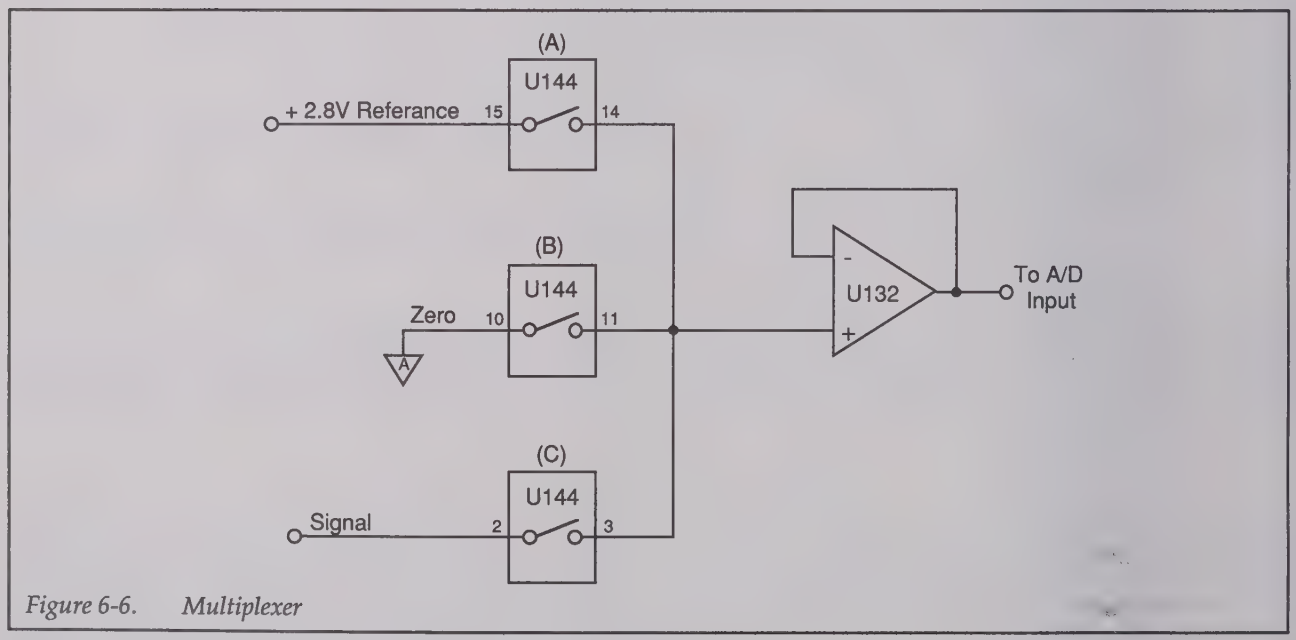


Figure 6-6. Multiplexer

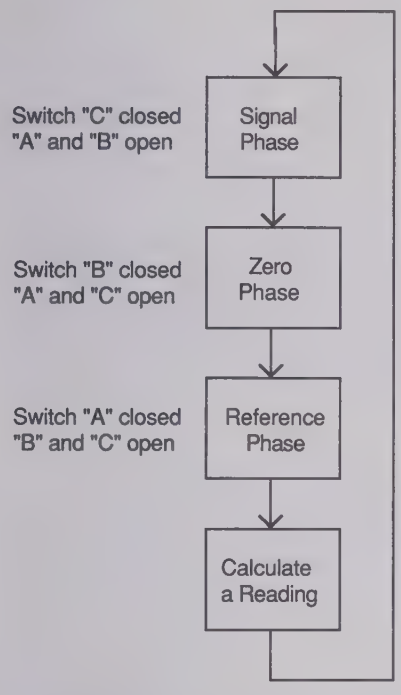


Figure 6-7. Multiplexer Phases

6.2.5 Analog Output

The analog output is provided by a differential amplifier circuit. The detailed circuit is shown on sheet 1 of schematic 486-106 or 487-106. A simplified circuit is shown in Figure 6-8.

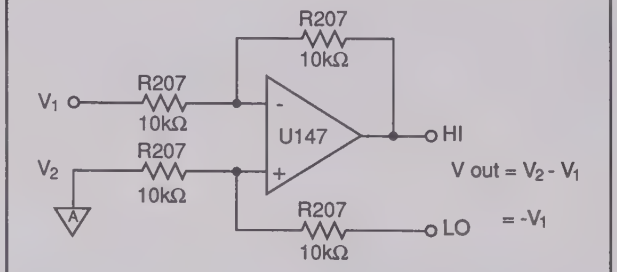


Figure 6-8. Analog Output Circuit (Simplified)

As shown in Figure 6-8, the analog output (V_{OUT}) is simply V_2–V_1. For example, if the input current to the instrument is 1mA on the 2mA range, –1V will be applied to V_1. Analog output is then calculated as follows:

$$V_{OUT} = V_2 - V_1$$
$$= 0V - (-1V)$$
$$= +1V$$

Not shown in the simplified circuit is CR117, which is a diode bridge that is connected to the 15V supplies. This bridge provides current drive and protection for the analog output.

6.2.6 Voltage Source (Model 487)

Figure 6-9 shows a simplified block diagram of the voltage source of the Model 487. The schematic for the voltage source is on drawing 487-106, page 4.

Serial data, which represents the programmed voltage source value, is loaded into the U151 DAC (Digital-to-

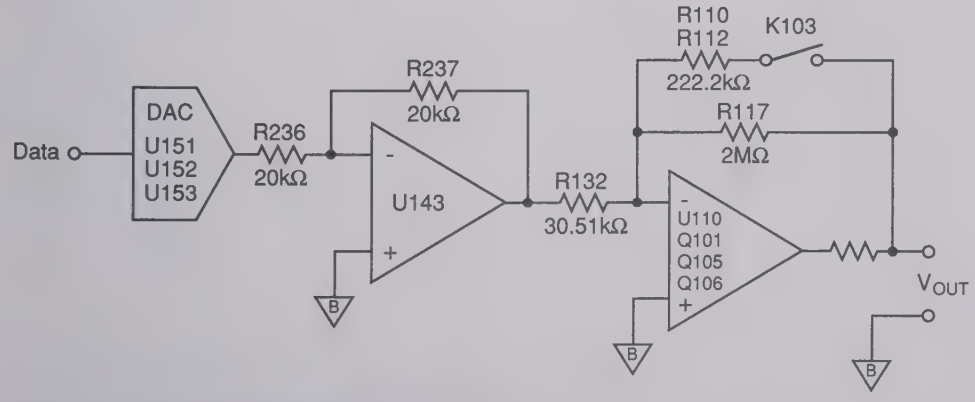


Figure 6-9. Simplified Model of V-Source (Model 487)

Analog Converter) through serial-to-parallel registers U153 and U152. A loaded value of $0000 will result in a DAC output (V_{OUT}) of 0V while a value of $FFFF will result in a V_{OUT} of +10V. U149 provides the 5V reference for the DAC.

The output of the DAC is inverted by U143 prior to being applied to the output amplifier. The inverting output amplifier consists of op amp U110, and N-channel power FETs Q101, Q105 and Q106. On the 500V range, feedback resistor R117 provides x65.536 gain. For the 50V range, K103 is closed changing amplifier gain to x6.5536. On the 500V range, this provides an output range of 0 –655.36V at 10mV per DAC count. On the 50V range, the output range is 0 –65.536V per DAC count.

U110 is configured as a high impedance amplifer that is used to control the power amplifier (Q101 and Q105). As the programmed voltage is increased, drain current through Q105 decreases causing an increase in drain current through Q101, which is connected to the +800V supply. As a result of the increased Q101 drain current, the voltage at the output increases.

With the 2.5ma I-limit selected, relay K102 is configured as shown in schematic 487-106, page 4. Q103 and R180 limit current to 3.5mA while the constant current source that is controlled by of Q106 sinks 1mA leaving a net of 2.5mA for the load on the V-Source.

When the 25µA I-limit is selected (K102 activated), U119 is used to sense current flow to the load. As load current increases to ~20µA, the output of U119 will change from 0V to –9V. With –9V at the output of U119, current will start to flow through VR102 overriding U110's control of Q105. U119 now forces the output voltage to limit at a point where 20µA is flowing in the load. When either current limit occurs, the transitor of photo-coupler AT101 turns on, placing the I-LIMIT control line at digital low.

When the voltage source is placed in standby, relay K100 opens, placing the output in a high impedance (open) state. Relay K102 controls polarity switching. For positive (+) outputs, K102 connects V_{OUT} to the red (HI) banana jack. For negative (–) outputs, K102 connects V_{OUT} to the black (LO) banana jack.

V-Source Power Supplies

The +800VB supply is derived by applying 250VAC to the voltage doubler circuit that consists of CR100, CR105, C103 and C109. Regulation for the supply is provided by C104, C105, and transistors Q100 and Q102. For safety, Q104 is used to discharge capacitors C103 and C109 when instrument power is turned off. When the instrument is turned off, a discharge circuit consisting of C102, CR102, R115 and R116 turns on Q104 for a short period of time to allow the capacitors to discharge to ground. R100 and R114 also help to discharge these capacitors. VR106 is used to protect the Model 487 if it is inadvertently connected to 230V ac line power while set for 115V operation.

The ±15VB supplies are used exclusively for the V-Source circuitry. Rectification for the ±15VB supplies is performed by CR103, while C100 and C101 provide filtering. U100 regulates the +15VB supply, and U101 regulates the –15VB supply. Output filtering is performed by C110 and C112.

The +5VB supply is derived from the 15VB supplies using the 5V regulator U102. Filtering is provided by C111.

6.3 ANALOG CONTROL CIRCUITRY

The analog circuits, can be found on drawing number 486-106 (page 3), or on 487-106 (page 3). These circuits control virtually all aspects of the analog section of the instrument, including the voltage source of the Model 487. The following information describes the key aspects of the analog control circuits.

Figure 6-10 shows a simplified block diagram of the analog control circuits. A synchronous serial data transmission scheme is used to pass digital control information through opto-isolators U103, U109 and U105 to several shift registers that store the control information (U136, U122 and U134). The three transmission lines are:

ANALOG DATA: transmits the serial control data
ANALOG CLOCK: controls the data transmission rate
ANALOG STROBE: latches control information into command registers

For the Model 487, data to the V-Source DAC is sent through opto-isolators U125, U131 and U133. The control circuit exclusive to the V-Source is located on schematic 487-106, page 4.

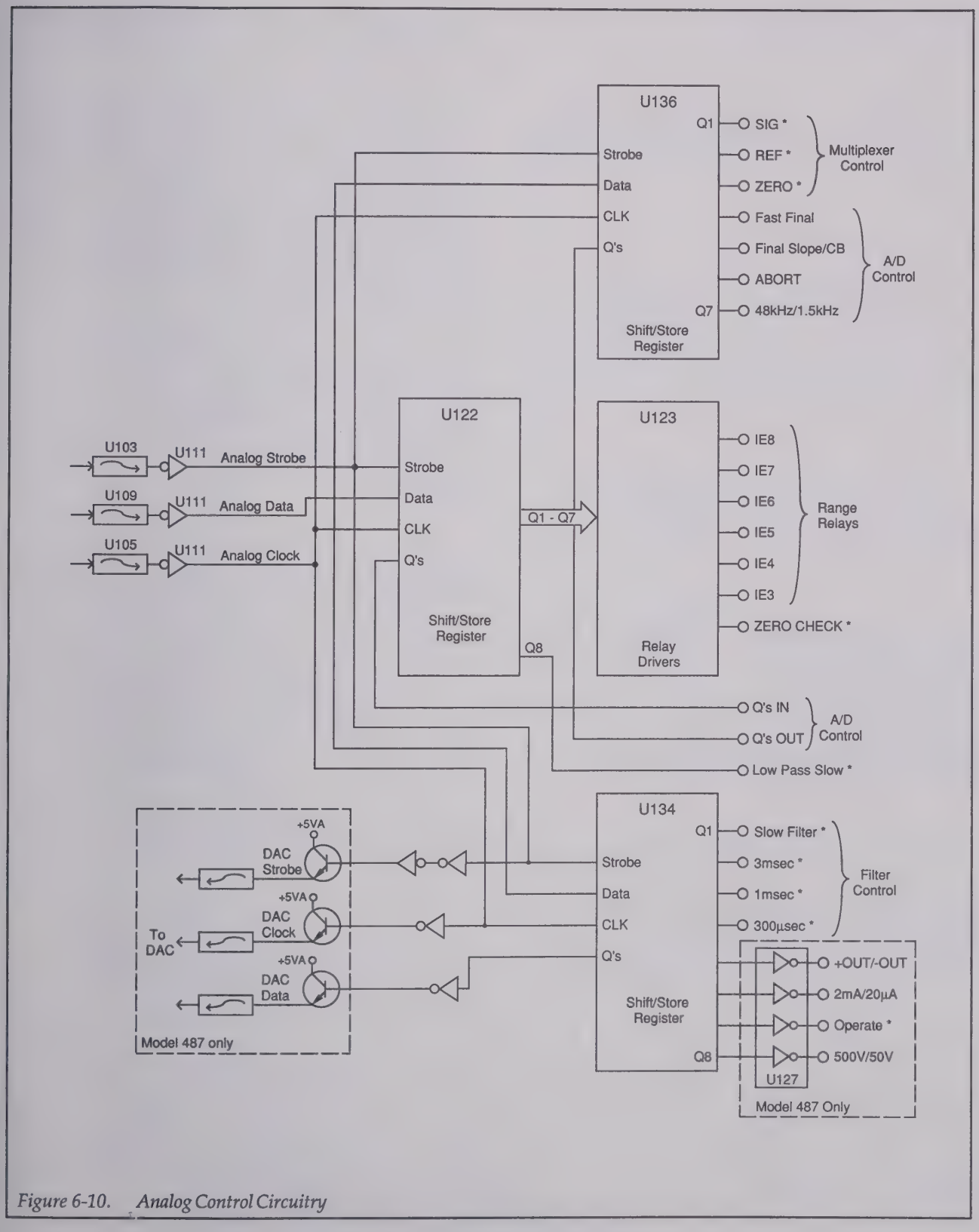


Figure 6-10. Analog Control Circuitry

A 24-bit control word, shown in Figure 6-11, is used to control the various functions.

The command register (U122 and U134) cannot directly drive the range relays V-Source relays (Model 487). Relay drive ICs (U123 and U127) provide the necessary drive capability.

6.4 A/D CONVERTER

The Model 486/487 uses a constant frequency, variable pulse width, analog-to-digital converter. The schematic diagram for the A/D converter is located on page 2 of drawing 486-106 for the Model 486, and on page 2 of drawing 487-106 for the Model 487. A simplified schematic diagram for the A/D converter is shown in Figure 6-12.

Reading conversions start with a charge balance phase and end with a single slope phase, thus producing two sets of counts from U129 back to the VIA of the microcomputer.

The A/D input is converted to a current by R187 and added to the offset current controlled by R186. This summed current is applied, via FET switch Q110, to the integrator which is made up of operational amplifier U113, Q108 and C141. This integrator ramps in a positive direction (since the current is negatively offset) until it reaches a threshold, or until a timebase interval occurs and switches on a balance current. This continues for a length of time that is determined by the value in register U126 which is programmed by the microprocessor.

Device U120 is an 8-bit magnitude comparator which continuously compares the set value to the count value in counter U128. When these two numbers match, the output on pin 19 of U120 stops the A/D converter, thus signaling the end of the charge-balance phase. After determining that the charge balance has stopped (by monitoring counts or timing out), the software sets the Final Slope/CE line high. This clears U128 making it ready for a new charge-balance phase, and starts the final-slope phase of the A/D converter.

The final-slope phase essentially removes all charge remaining on the integrator putting the output of U113 at 0V. Counts are accumulated during the final-slope and used for calculation of the effective input signal. The A/D converter is run through a number of phases that are used to null any error signals present in the A/D or analog front end.

The time base for the A/D converter is provided by an oscillator that consists of Q116 and Q117 and crystal Y100. The 3.84MHz time base, which is a multiple of 60Hz, is divided by counters U135 and U138 to provide system timing functions for charge balance control. The 3.84MHz is fed directly to AND gate U129 where it is gated on and off by the rest of the A/D function. The A/D power supply reference voltages, –10V, and +5V are derived from operational amplifier U114 and associated circuitry. These are reference voltages used in generating currents and thresholds for the A/D converter.

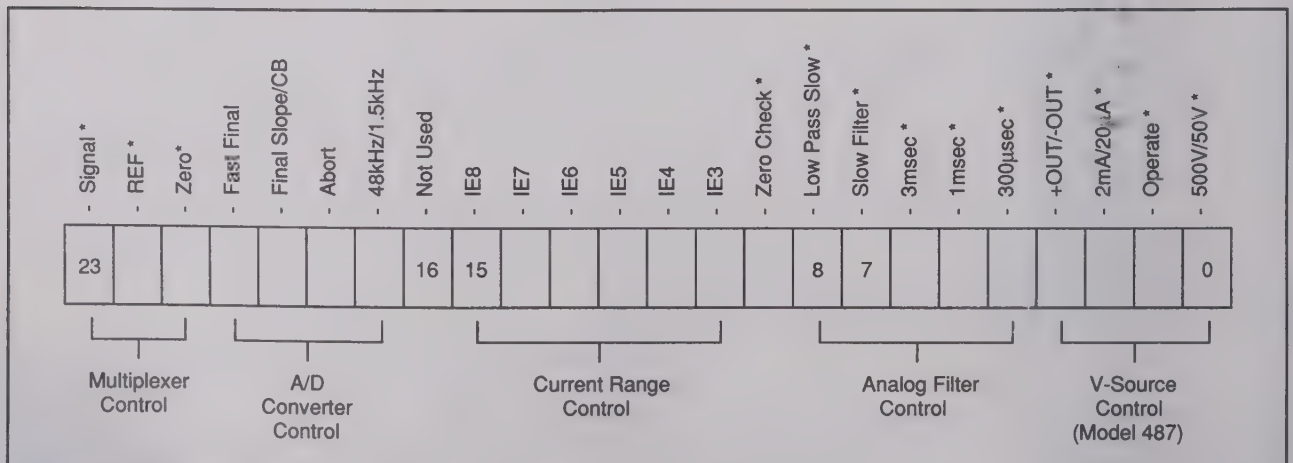


Figure 6-11. Control Word

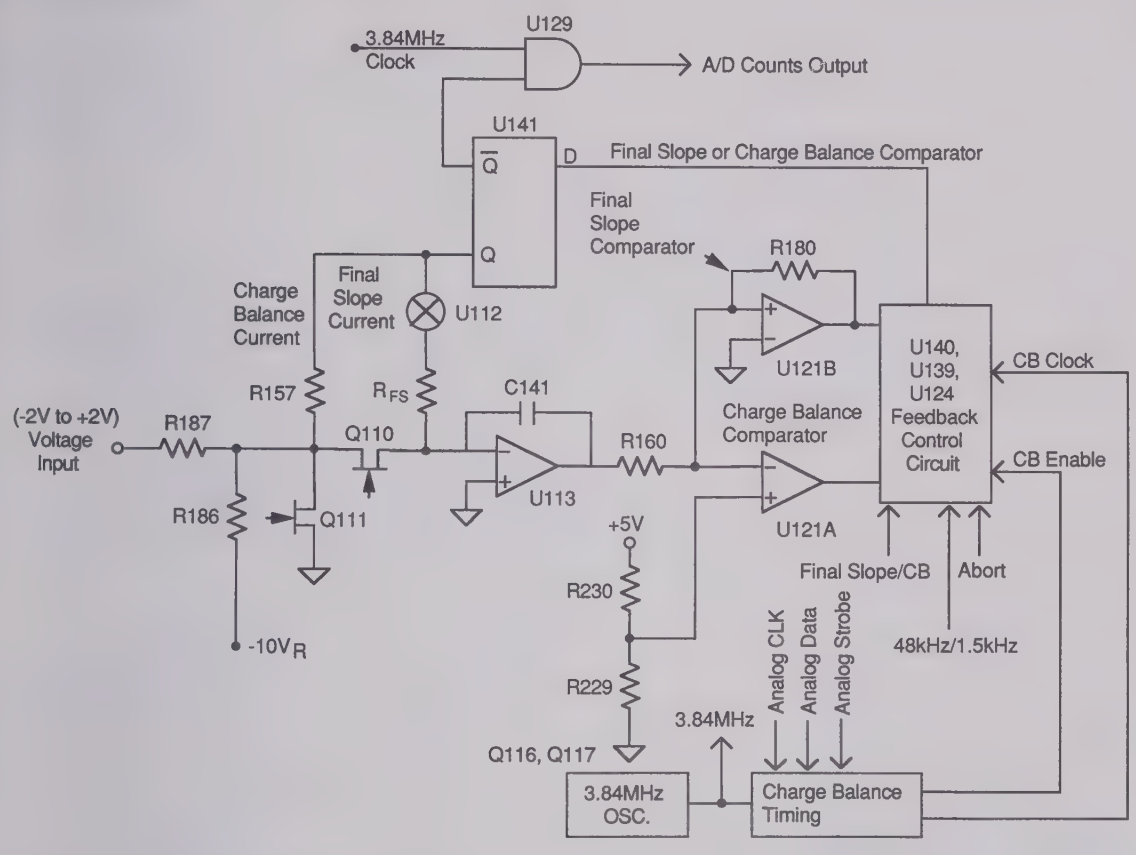


Figure 6-12. A/D Converter Simplified Schematic

6.5 DIGITAL CIRCUITS

The paragraphs below give an overview of the digital circuits, which can be found on drawing numbers 487-146 and 486-116 (487-116 for the Model 487) at the end of Section 8.

NOTE

The digital board shown in drawing 487-146 is also used for a different instrument (Model 428) and shows some information that does not pertain to the Model 486/487.

6.5.1 Digital Block Diagram

Figure 6-13 shows a block diagram of the most important circuits. Key sections include the microcomputer (RAM, ROM, VIA, EEROM, and GPIA), the display board, and the IEEE-488 interface. The various sections are covered in the following paragraphs.

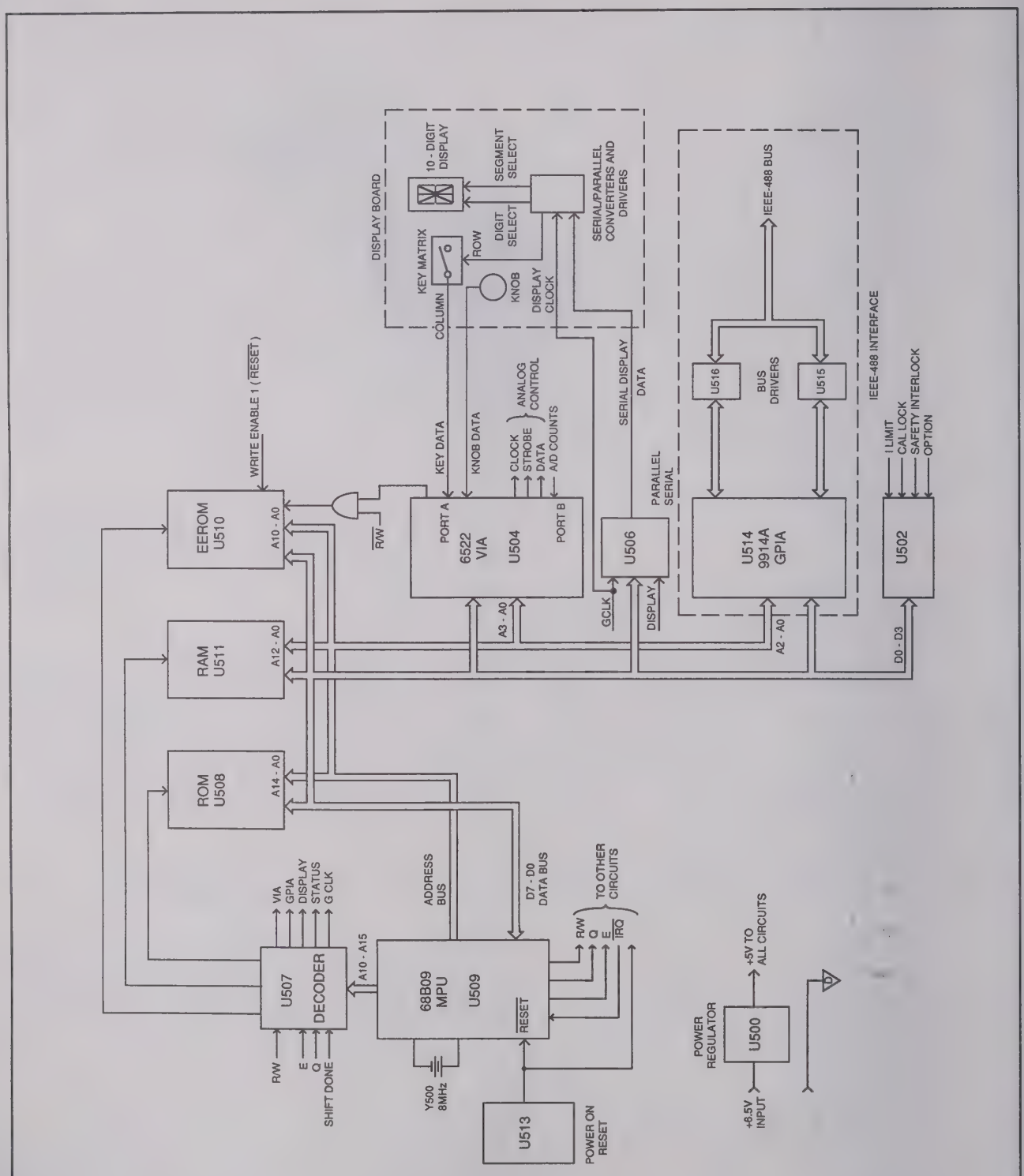


Figure 6-13. Digital Block Diagram

6.5.2 Microcomputer

The microcomputer controls all operating aspects of the instrument. The various sections of the microcomputer include the 68B09 MPU, the memory circuits, and I/O (GPIA) circuits.

Microprocessor

U509 is a 68B09 8-bit microprocessor that controls the instrument. The processor has an 8-bit data bus (D7-D0), a 16-bit address bus (A15-A0), as well as a number of control lines.

Y500 is an 8MHz crystal that provides a time base for the internal MPU clock. The clock signal is internally divided down to 2MHz and is used as a bus clock via the E and Q lines.

Power-on reset for the MPU is provided by U513. The reset signal is also used to inhibit writing to the EEROM during power-up.

Memory Circuits

U508, a 64K byte PROM which uses 48k bytes, contains the instruction coding for the MPU. Working storage for the MPU is provided by U511, an 8K byte RAM. Non-volatile storage for data such as calibration constants, zero-correction constants and power-on defaults is provided by EEPROM U510.

Address Decoder

U507 is a PAL that performs the address decoding for the various memory and I/O circuits, and is also instrumental in the operation of the display serial port. U507 monitors the states of the A15-A10 address lines, and it selects the appropriate section of the memory map accordingly. A memory map is shown in Figure 6-14.

I/O Port

U504, a 6522 VIA (Versatile Interface Adapter) provides much of the I/O for the microcomputer. Port A reads keyboard and knob data, while port B provides a serial port for controlling the analog board, and a counter for counting A/D counts from the analog board.

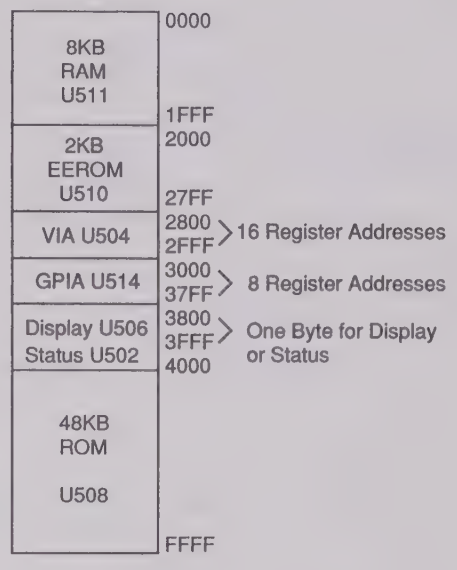


Figure 6-14. Memory Map

Display Serial Port

The display serial port provides high-speed serial data transmission to the display and keyboard circuits located on the display board. Figure 6-15 shows a simplified block diagram of the serial port.

The 2MHz clock (GCLK) for the port is provided by the PAL, U507. U506 is a parallel-to-serial converter used to shift out display and keyboard data to circuits located on the display board. U503 is a bit-shift counter and provides the SHIFT DONE signal when all eight bits of U506 are shifted out at the 2MHz clock rate.

The basic data transmission sequence is as follows:

1. The byte to be transmitted is written to U506. The act of writing this byte only parallel loads U506, but it also clears the shift counter, U503, via its CLR line. Clearing U503 enables the GCLK (gated clock) signal supplied by U507. GCLK becomes the clock signal after inversion by U502.
2. The GCLK pulses applied to U506 cause the 8–bit data word to be shifted out the DISPLAY DATA line. At the same time, the display clock pulses cause the shift counter, U503, to count up, one count per clock cycle.

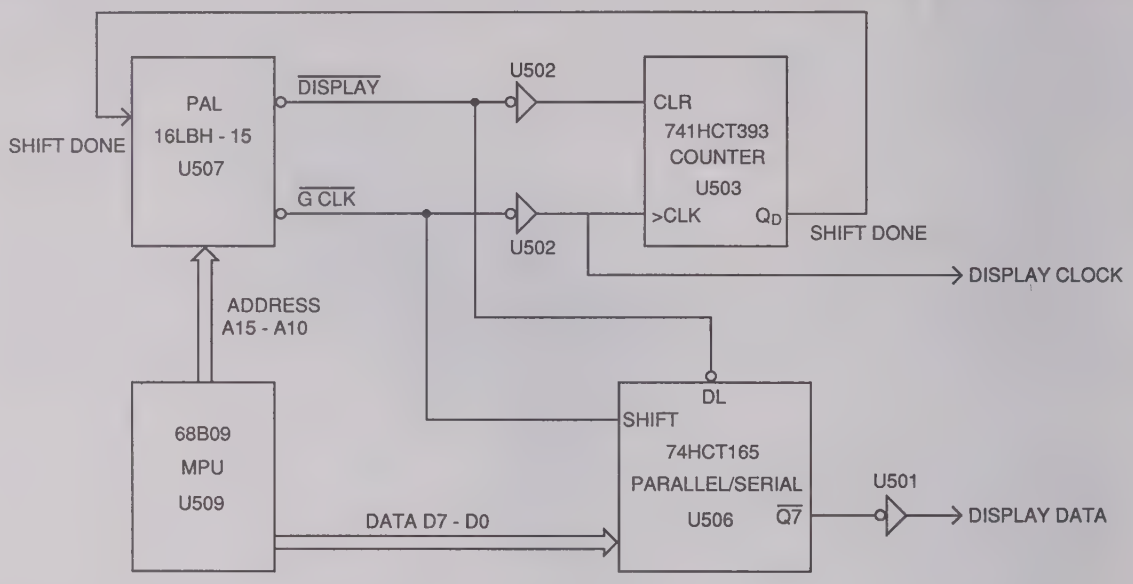


Figure 6-15. Simplified Block Diagram of Serial Port

3. After all eight bits are shifted out, the shift counter generates the SHIFT DONE signal to indicate that the entire byte has been shifted out. This signal is fed back to the PAL, U507, which halts the GCLK signal to stop the shifting process.
4. The process in steps 1 through 3 repeats for four successive bytes until all the necessary information is transmitted to the display and keyboard circuits.
5. The DISPLAY LEFT and DISPLAY RIGHT lines, which are controlled by the PA6 and PA7 terminals of U504, are brought low to enable the information to be displayed on the display board.

6.5.3 Display/Keyboard

The display and keyboard circuits are shown on drawing 486-116 for the Model 486 or 487-116 for the Model 487, located at the end of Section 8. Figure 6-16 shows a block diagram of the display and keyboard circuits.

Display Multiplexing

The digits of the 10-digit left display, and the group of separate LEDs are multiplexed, which means that only one digit (or the group of separate LEDs) is actually on at any given time. Because of the rapid multiplexing rate, display flicker is not visible to the user.

For each digit, display data is clocked in via the DISPLAY DATA line using the DISPLAY CLOCK and the transmission sequence discussed in the previous paragraphs. This data is shifted into shift registers located on the display board. U401 and U409 hold segment data, and U406 and two bits of U411 store selected digit data. One bit of U411 is used to control the separate LEDs, while five bits of U411 are used to strobe the five rows of the keyboard matrix.

After all data are shifted in, the DISPLAY LEFT line is brought low to enable into the U401 and U409 outputs. This action causes the pertinent segments of the selected digit (or the selected separate LEDs) to turn on. The process repeats for a total of 11 times per display update cycle so that each display digit or LED can be turned on as appropriate.

Segment drive capabilities are an integral part of U401 and 409, and external current-limiting resistors are required and provided by R405 and R406. Drive capability for U406 and U411 are provided by U405 and U410 respectively.

The 8-digit right display operates in a similar fashion. Display data is clocked into three shift registers. U408 and U412 hold segment data, while U404 stores selected digit data. After all data are shifted in, the DISPLAY RIGHT line is brought low to enable the U408 and U412

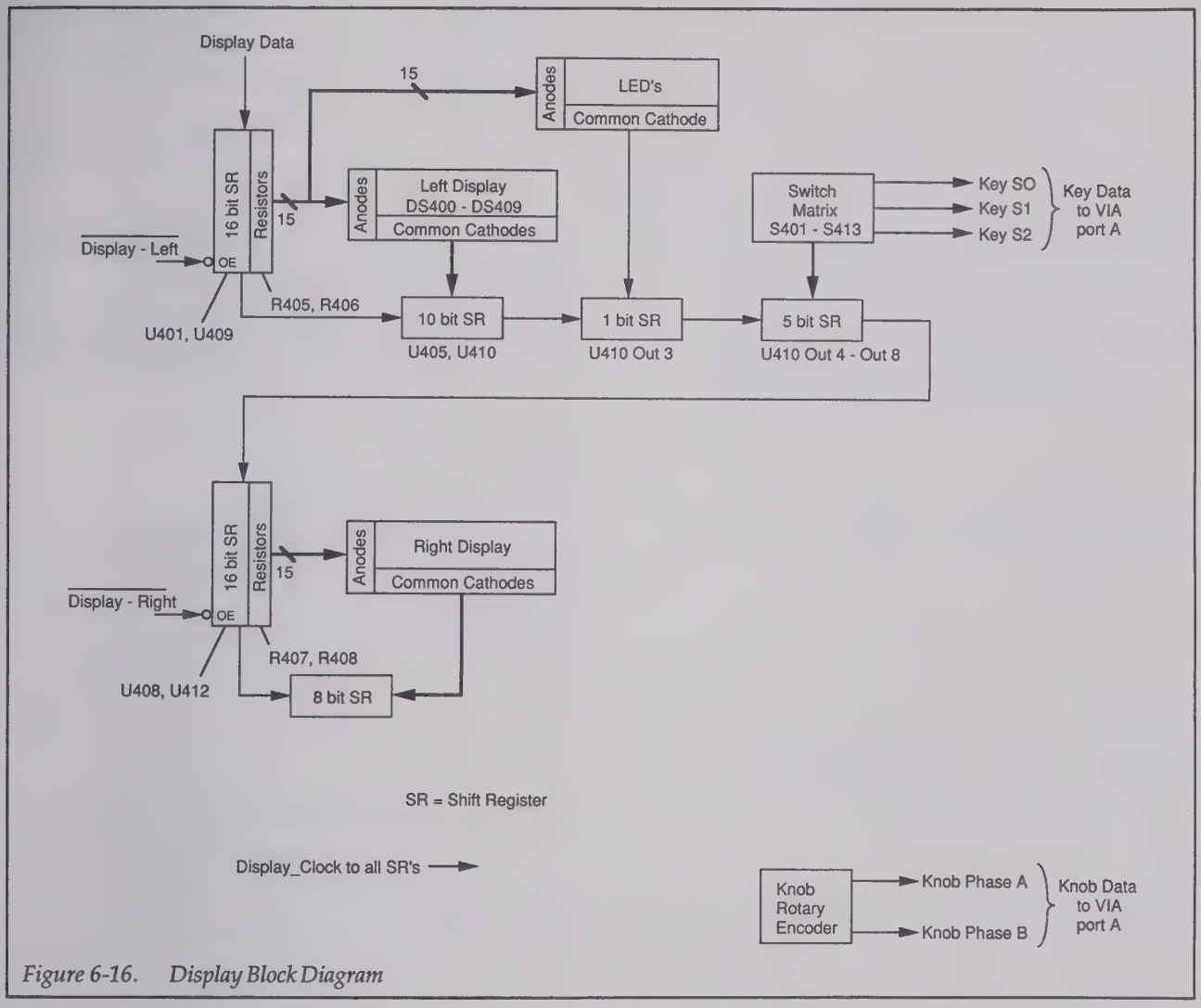


Figure 6-16. Display Block Diagram

outputs causing the segments of the selected digit to turn on. The process repeats for a total of eight times per display update cycle.

Current limit for U408 and U412 are provided by R407 and R408. Separate drive for U404 is not required.

Reading the Keyboard

The front panel keys are organized as a 5-row by 3-column matrix. In order to determine which key is closed, each row in succession is strobed by setting the appropriate output of U411 high. For each row, the three columns are read through the VIA on the digital board. Knob data is read through the VIA as well. The rotary knob outputs a digital 2-bit gray-code (one line changes state for every knob detent rotation).

6.5.4 IEEE-488 Interface

The IEEE-488 interface is located on drawing 487-106, page 2 at the end of Section 8. A simplified circuit of the interface is shown in Figure 6-13.

The interface includes three ICs. U514 is a 9914A GPIA (General Purpose Interface Adapter) that performs many bus control functions, such as handshaking automatically to minimize MPU overhead. Bus drive capabilities are provided by U515 and U516. U516 supports the data

lines (DIO1-DIO8), and U515 supports management and handshake lines.

6.6 POWER SUPPLIES

Figure 6-17 shows a block diagram of the power supply section. The power supply schematic is located on drawing 486-106 (page 3) for the Model 486 or 487-106 (page 3) for the Model 487.

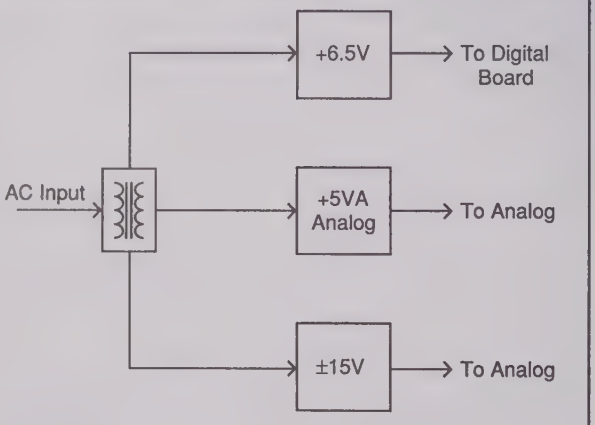


Figure 6-17. Power Supply Block Diagram

6.6.1 AC Line Input

The AC power line voltage is applied through J1001 to the power transformer, T100. S101 is the on/off switch, and F100 is the line fuse that provides protection to the line voltage input circuits. S100 switches between 90-125V and 180-250V AC operation.

6.6.2 ±15V Supplies

The ±15V power supplies provide power to all the amplifier stages on the analog board. Rectification for the ±15V supplies is performed by CR108, while C114 and C108 provide filtering. U106 regulates the +15V supply, and U108 regulates the –15V supply. Output filtering is performed by C122 and C123.

6.6.3 +5VA Supply

The +5VA supply powers the analog control circuits and relays located on the analog board. CR106 rectifies incoming AC, and C117 filters the rectifier output. U107 regulates the supply to its nominal +5V value, and C121 provides output filtering.

6.6.4 +6.5V Supply

The +6.5V supply powers circuits on the digital board. CR109 rectifies the 8V AC input voltage, while C115 filters the output. The output of the +6.5V supply is further regulated to +5V by a separate power regulator located on the digital board (U500). This +5V supply also supplies the display board.

SECTION 7
Maintenance

7.1 INTRODUCTION

This section contains information necessary to maintain, calibrate, and troubleshoot the Model 486/487. The line fuse replacement procedure is also included.

WARNING

The procedures in this section are for use only by qualified service personnel. Do not perform these procedures unless qualified to do so. Many of the steps in this section may expose you to potentially lethal voltages that could result in personal injury or death if normal safety precautions are not observed.

7.2 LINE FUSE REPLACEMENT

A rear panel fuse located adjacent to the line voltage switch protects the power line input of the instrument. If the fuse needs to be replaced (line voltage switch setting changed or suspected blown fuse), perform the following steps:

WARNING

Make sure the instrument is disconnected from the power line and other equipment before replacing the fuse.

1. With the power off, place the end of a flat-blade screwdriver into the slot in the rear panel LINE FUSE holder. Push in gently and rotate the fuse carrier one-quarter turn counterclockwise. Release pressure on the holder and its internal spring will push the fuse and carrier out of the holder.
2. Remove the fuse and replace it with the type recommended in Table 7-1.

CAUTION

Do not use a fuse with a higher current rating than specified, or instrument damage may occur. If the instrument repeatedly blows fuses, locate and correct the cause of the trouble before replacing the fuse. See troubleshooting information in this section.

3. Install the new fuse and the fuse carrier into the holder by reversing the above procedure.

Table 7-1. Line Fuse Selection

Line Voltage	Fuse Type	Keithley Part No.
90-125V	1/2A, 250V, 3AG, Slo Blo	FU-4
180-250V	1/4A, 250V, 3AG, Slo Blo	FU-17

7.3 CALIBRATION

Calibration should be performed every 12 months, or if the performance verification procedures in Section 5 show that the Model 486/487 is out of specification. If any of the calibration procedures in this section cannot be performed properly, refer to the troubleshooting information in this section. If the problem persists, contact your Keithley representative or the factory for further information.

7.3.1 Recommended Calibration Equipment

Table 7-2 lists recommended calibration equipment. Alternate equipment may be used as long as equipment accuracy is at least as good as the specifications listed in the table.

Table 7-2. Calibration Equipment

Item	Manufacturer	Model	Description	Specification
A*	Keithley	263	Calibrator/Source (5-1/2 digits)	2nA, 20nA ranges: ±(0.065% + 10 counts) 200nA range: ±(0.035% + 10 counts)
B*	Keithley	6171	3-slot male to 2-lug female triax adapter	2μA-2mA ranges: ±(0.025% + 10 counts)
C*	Keithley	7024-3	2-slot triax cable	—
D**	Keithley	197	DMM (DC Volts) (5-1/2 digits)	200V, 1000V ranges: ±(0.015% + 2 counts)
E**	Keithley	1973	IEEE-488 Interface for Model 197	—
F**	Pomona	B-24	Banana Plug Cable (2 required)	—

*Items A, B and C are used to calibrate the picoammeter of the Models 486 and 487.
**Items D, E and F are used to calibrate the voltage source of the Model 487. Note that item E (Model 1973) is only required if you wish to control the Model 197 DMM over the IEEE-488 bus.

7.3.2 Environmental Conditions

Calibration should be performed under laboratory conditions having an ambient temperature of 23°C ±1°C and a relative humidity of less than 70%.

7.3.3 Warm-Up Period

Turn on the instrument power and allow it to warm up for at least two hours before beginning the calibration procedure. If the instrument has been subjected to extremes of temperature or humidity, allow at least one additional hour for the instrument to stabilize before beginning the calibration procedure.

7.3.4 CAL LOCK Switch

A CAL LOCK switch, accessible from the rear panel (see Figure 7-1), disables or enables calibration. When calibration is disabled (switch in "out" position), calibration cannot be performed. The following message will be briefly displayed when attempting to calibrate the instrument while the switch is in the disabled position.

CAL LOCKED

Calibration can only be accomplished with the calibration switch in the enabled position.

To enable calibration, push in the CAL LOCK switch to the "in" position using an insulated tool (through the small access hole in the rear panel).

After calibration is complete, again press the CAL LOCK switch to place it in the "out" position to disable calibration.

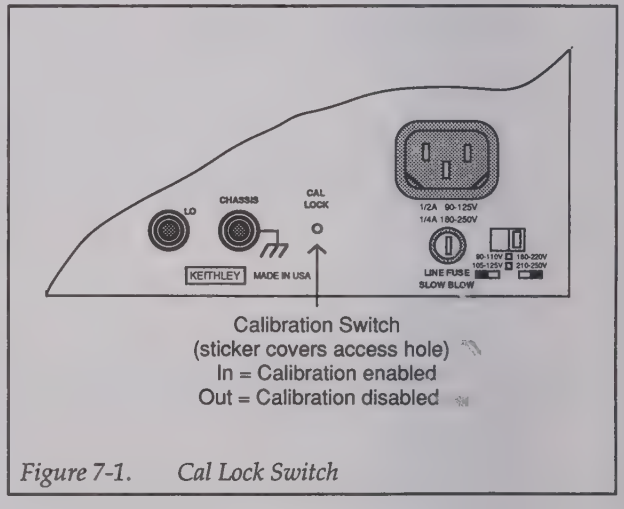


Figure 7-1. Cal Lock Switch

7.3.5 Front Panel Calibration

Picoammeter Calibration

In general, current calibration consists of applying a source value of +190,000 counts to each range and performing the calibration routine. Table 7-3 lists the required calibration current for each range. For front panel

calibration, ignore the column labeled "IEEE-488 Bus Command".

Table 7-3. Picoammeter Calibration

486/487 Range	263 V/R Amps Range	263 Calibration Current	IEEE-488 Bus Command
2nA	2nA	1.90000nA	L3, 1.9E–9X
20nA	20nA	19.0000nA	L3, 19E–9X
200nA	200nA	190.000nA	L3, 190E–9X
2µA	2µA	1.90000µA	L3, 190E–9X
20µA	20µA	19.0000µA	L3, 19E–6X
200µA	200µA	190.000µA	L3, 190E–6X
2mA	2mA	1.90000µA	L3, 1.9E–3X

Perform the following steps to calibrate the current ranges of the Model 486/487:

1. Return the Model 486/487 to factory default conditions as follows:
   A. Press and release MENU until the following message is displayed:

      DEFAULTS OK

   B. Use the rotary knob to display the following message:

      DEFAULTS FACTORY

   C. Press MENU. The instrument will return to factory default conditions.
2. Connect the Model 263 current source to the Model 486/487 as shown in Figure 7–2. Configure the Model 263 for V/R AMPS and make sure that GUARD is disabled. Also, make sure the Model 263 ground link is installed.
3. On the Model 486/487, disable autorange (Press SHIFT and then AUTO RANGE). Make sure the Model 486/487 is on the 2nA range.
4. Set the Model 263 to the 2nA range and apply 1.90000nA to the Model 486/487.
5. On the Model 486/487, disable zero check to measure the calibration current source.
6. Press and release MENU until the following message is displayed:

   CALIBRATE NO

7. Use the rotary knob to display the following message:

   CALIBRATE YES

8. On the Model 486/487, press MENU. While the instrument is performing calibration, the following message will be displayed:

   CALIBRATE WORKING

9. After the selected range is calibrated, the Model 486 will return to the normal measurement display state. The Model 487 will display the next menu item, which is CAL V SOURCE. For the Model 487, press MENU to return to the normal measurement display state.
10. On the Model 486/487, enable zero check.
11. Set the Model 486/487 to the 20nA range, set the Model 263 to source 19.0000nA on the 20nA range, and repeat steps 5 through 10.
12. Set the Model 486/487 to the 200nA range, set the Model 263 to source 190.000nA on the 200nA range, and repeat steps 5 through 10.
13. Set the Model 486/487 to the 2µA range, set the Model 263 to source 1.90000µA on the 2µA range, and repeat steps 5 through 10.
14. Set the Model 486/487 to the 20µA range, set the Model 263 to source 19.0000µA on the 20µA range, and repeat steps 5 through 10.
15. Set the Model 486/487 to the 200µA range, set the Model 263 to source 190.000µA on the 200µA range, and repeat steps 5 through 10.
16. Set the Model 486/487 to the 2mA range, set the Model 263 to source 1.90000mA on the 2mA range, and repeat steps 5 through 10.
17. Place the Model 263 in standby.

NOTE

For the Model 486, place the CAL LOCK switch in the "out" position to disable calibration. Do the same to the Model 487 if you are not going to calibrate the voltage source.

NOTE

During calibration, the message "CAL ERROR" indicates that the calibration source value is not within allowable limits. All calibration source values must be 190000 counts ±9500 counts. In the event of this error, the calibration will simply not be performed. If the error persists for cal values that are within the allowable limits, then servicing will be necessary.

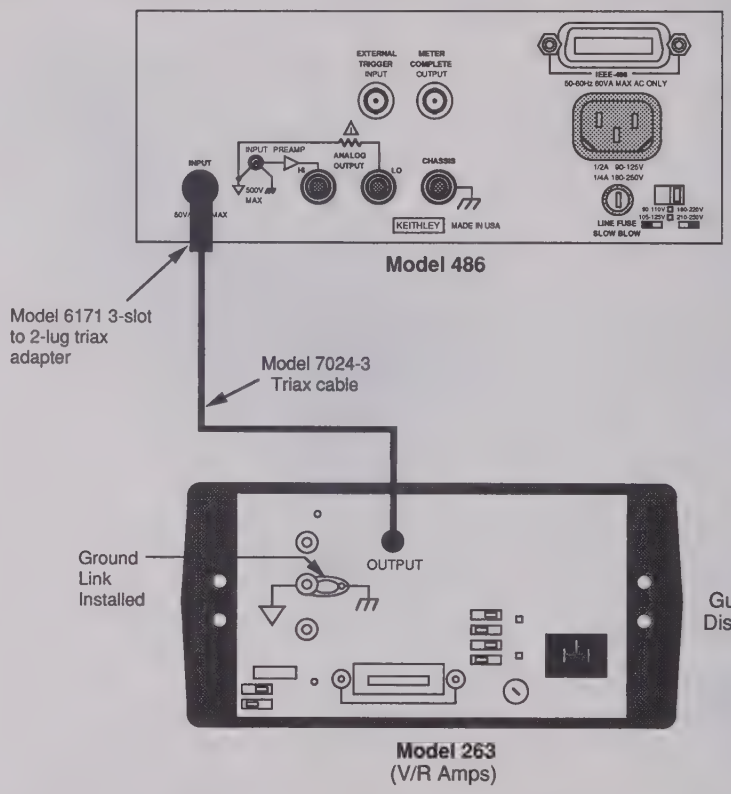


Figure 7-2. Setup for Picoammeter Calibration

Voltage Source Calibration (Model 487)

In general, the voltage source of the Model 487 is calibrated by adjusting the output until 0V and full scale are measured by a DMM and then performing the calibration routine.

Perform the following steps to calibrate the V-Source of the Model 487:

WARNING
The following procedure uses hazardous voltages that could cause severe injury or death. Exercise extreme caution when performing this procedure.

1. Zero the 200mV range of the Model 197 DMM and select autorange.
2. Make sure the V-Source (voltage source) of the Model 487 is in standby, then connect the Model 197 DMM to it as shown in Figure 7-3.
3. While in standby, set the V-Source to the 50V range. Note: Keep pressing and releasing the ▶ key until the 50V range is displayed (i.e. "00.000V" is 0V on the 50V range).
4. Place the V-Source in operate.
5. Press and release MENU until the following message is displayed:

   CAL V SRC NO

6. Use the rotary knob to display the following message:

   CAL V SRC YES

7. Press MENU. The following message will be displayed:

   SET ZERO

8. Adjust the V-Source output of the Model 487 to measure (as close as possible) 00.000mV on the Model 197.

9. Press MENU to calibrate 0V on the 50V range. The instrument will then source 50V (nominal) and display the following message:

   SET POS FS (Set positive full scale)

10. Adjust the V-Source output of the Model 487 to measure +50.000V on the Model 197.

NOTE
If the output cannot be adjusted high enough to measure 50.000V on the Model 197, set the V-Source to its maximum output setting (50.500V displayed on the Model 487).

11. Press MENU to calibrate the 50V range at full scale. The instrument will exit the calibration mode.
12. If the Model 197 is not reading +50.000V, repeat steps 5 through 11. Otherwise, proceed to the next step.
13. Set the V-Source to output 000.00V on the 500V range.
14. Press and release MENU until the following message is displayed:

    CAL V SRC NO

15. Use the rotary knob to display the following message:

    CAL V SRC YES

16. Press MENU. The following message will be displayed:

    SET ZERO

17. Adjust the V-Source output of the Model 487 to measure (as close as possible) 00.000mV on the Model 197.
18. Press MENU to calibrate 0V on the 500V range. The instrument will then source 500V (nominal) and display the following message:

    SET POS FS

19. Adjust the V-Source output of the Model 487 to measure +500.00V on the Model 197.

NOTE
If the output cannot be adjusted high enough to measure 500.00V on the Model 197, set the V-Source to its maximum output setting (505.00V displayed on the Model 487).

20. Press MENU to calibrate the 500V range at full scale. The instrument will exit the calibration mode.
21. If the Model 197 is not reading +50.000V, repeat step 13 through 20.
22. Place the V-Source of the Model 487 in standby.

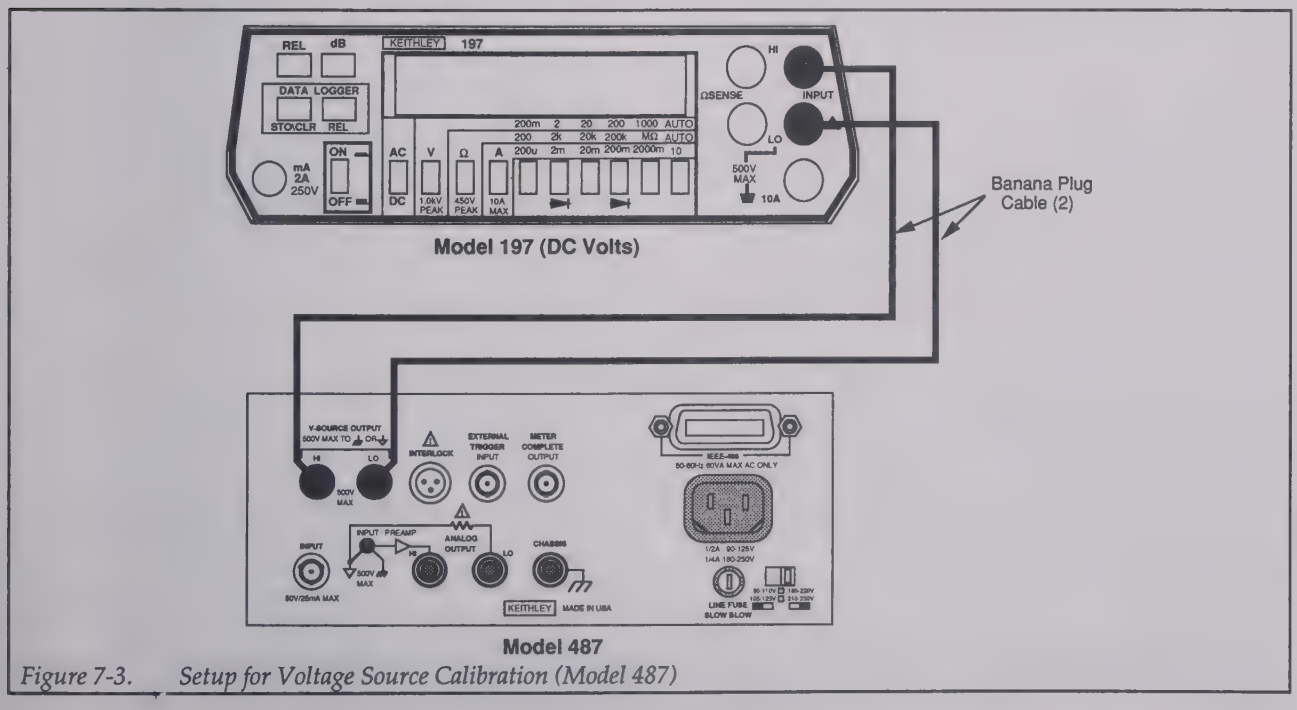


Figure 7-3. Setup for Voltage Source Calibration (Model 487)

7.3.6 IEEE-488 Bus Calibration

The following procedures will demonstrate how to use the "L" command over the IEEE-488 bus to calibrate the Model 486/487. For simplicity, all other operations of the Model 486/487 and calibration equipment will be controlled manually from the front panel.

The following simple program in HP BASIC 4.0 can be used to send calibration commands to the Model 486/487. When this program is run, it will prompt you to enter the calibration command string. After sending the command, the Model 486/487 will send a reading back to the computer that will be displayed. Also, this program uses the U3 status word to acquire and display the calibration value that was sent over the bus. For this program, the primary IEEE-488 address of the Model 486/487 is set to 22.

```
HP BASIC 4.0 PROGRAM                    COMMENTS

10  REMOTE 722                          ! Send remote enable.
20  PRINT "ENTER CALIBRATION COMMAND"   ! Prompt for command.
30  LINPUT A$                           ! Input command string from keyboard.
40  OUTPUT 722; A$                      ! Send command string to 486/487.
50  ENTER 722; B$                       ! Get a reading from 486/487.
60  PRINT B$                            ! Display reading on computer CRT.
70  OUTPUT 722; "U3X"                   ! Program for U3 status word.
80  ENTER 722; C$                       ! Get calibration value from 486/487.
90  PRINT C$                            ! Display calibration value.
100 GOTO 20                             ! Loop back.
110 END
```

In practice, it is recommended that calibration be fully automated. A well designed computer program can control all instrument operations (Model 486/487, Model 263, and Model 197/1973).

Picoammeter Calibration

In general, current calibration consists of applying a source value of +190,000 counts to each range and then sending the appropriate calibration command. Table 7-3 lists the required calibration current and calibration command for each range.

NOTE
After a calibration command is sent over the bus, front panel controls are locked out. To perform a front panel operation make sure you first press the LOCAL key.

Perform the following steps to calibrate the current ranges of the Model 486/487:

1. Make sure CAL LOCK is pressed "IN" and return the Model 486/487 to factory default conditions as follows:
   A. Press and release MENU until the following message is displayed:

      DEFAULTS OK

   B. Use the rotary knob to display the following message:

      DEFAULTS FACTORY

   C. Press MENU. The instrument will return to factory default conditions.
2. Connect the Model 263 current source to the Model 486/487 as shown in Figure 7-2. Configure the Model 263 for V/R AMPS and make sure that GUARD is disabled and the ground link is installed.
3. On the Model 486/487, disable autorange (Press SHIFT and then AUTO RANGE). Place the Model 486/487 on the 2nA range.
4. Set the Model 263 to the 2nA range and apply 1.90000nA to the Model 486/487.
5. On the Model 486/487, disable zero check to measure the calibration current source.
6. Send the following command over the IEEE-488 bus:

   L3,1.9E–9X

   While the instrument is performing calibration, the following message will be displayed:

   CALIBRATE WORKING

   After the selected range is calibrated, the instrument will return to the normal measurement display state.

7. On the Model 486/487, enable zero check.
8. Place the Model 486/487 on the 20nA range, set the Model 263 to source 19.0000nA on the 20nA range,

and repeat the basic procedure in steps 5 through 7 using the following calibration command:

L3,19E–9X

9. Set the Model 486/487 to the 200nA range, set the Model 263 to source 190.000nA on the 200nA range, and repeat the basic procedure in steps 5 through 7 using the following calibration command:

   L3,190E–9X

10. Set the Model 486/487 to the 2μA range, set the Model 263 to source 1.90000μA on the 2μA range, and repeat the basic procedure in steps 5 through 7 using the following calibration command:

    L3,1.9E–6X

11. Set the Model 486/487 to the 20μA range, set the Model 263 to source 19.0000μA on the 20μA range, and repeat the basic procedure in steps 5 through 7 using the following calibration command:

    L3,19E–6X

12. Set the Model 486/487 to the 200μA range, set the Model 263 to source 190.000μA on the 200μA range, and repeat the basic procedure in steps 5 through 7 using the following calibration command:

    L3,190E–6X

13. Set the Model 486/487 to the 2mA range, set the Model 263 to source 1.90000mA on the 2mA range, and repeat the basic procedure in steps 5 through 7 using the following calibration command:

    L3,1.9E–3X

14. Place the Model 263 in standby.

NOTE

For the Model 486, place the CAL LOCK switch in the "out" position to disable calibration. Do the same to the Model 487 if you are not going to calibrate the voltage source.

Voltage Source Calibration (Model 487)

In general, the voltage source of the Model 487 is calibrated by adjusting the output until 0V and full scale are measured by a DMM and then sending the calibration command.

NOTE

After a calibration command is sent over the bus, front panel controls are locked out. To perform a front panel operation make sure you first press the LOCAL key.

Perform the following steps to calibrate the V-Source of the Model 487:

WARNING

The following procedure uses hazardous voltages that could cause severe injury or death. Exercise extreme caution when performing this procedure.

1. Zero the 200mV range of the Model 197 DMM and select autorange.
2. Make sure the V-Source (voltage source) of the Model 487 is in standby, then connect the Model 197 DMM to it as shown in Figure 7-3.
3. While in standby, set the V-Source to the 50V range. Note: Keep pressing and releasing the ▶ key until the 50V range is displayed (i.e. "00.000V" is 0V on the 50V range).
4. Place the V-Source in operate.
5. Send the following command over the bus to prepare the 50V range for calibration:

   L6X

6. Adjust the V-Source output of the Model 487 to measure (as close as possible) 00.000mV on the Model 197.
7. Send the following command over the bus to calibrate 0V on the 50V range:

   L4X

8. Adjust the V-Source output of the Model 487 to measure +50.000V on the Model 197.

NOTE

If the output cannot be adjusted high enough to measure 50.000V on the Model 197, set the V-Source to its maximum output setting (50.500V displayed on the Model 487).

9. Send the following command to calibrate the 50V range at full scale:

L5X

10. If the Model 197 is not reading +50.000V, repeat steps 5 through 9. Otherwise, proceed to the next step.
11. Set the V-Source to output 000.00V on the 500V range.
12. Send the following command over the bus to prepare the 500V range for calibration:

L6X

13. Adjust the V-Source output of the Model 487 to measure (as close as possible) 00.000mV on the Model 197.
14. Send the following command over the bus to calibrate 0V on the 500V range:

L4X

15. Adjust the V-Source output of the Model 487 to measure +500.00V on the Model 197.

NOTE
If the output cannot be adjusted high enough to measure 500.00V on the Model 197, set the V-Source to its maximum output setting (505.00V displayed on the Model 487).

16. Send the following command to calibrate the 500V range at full scale:

L5X

17. If the Model 197 is not reading +500.00V, repeat steps 12 through 16.
18. Place the V-Source of the Model 487 in standby.

Calibration Errors

CAL ERROR — The message "CAL ERROR" indicates that the calibration source value is not within allowable limits. All current calibration source values must be 190000 counts 9500 counts. In the event of this error, the calibration will simply not be performed. To clear the displayed error message, press any front panel key. If this error persists when sending valid calibration values, then service will be necessary.

CAL VALUE — The briefly displayed message "CAL VALUE" indicates that the calibration value conflicts with the currently selected range. For example, sending a cal value of 190µA on the 20µA range will cause this error to occur. In the event of this error, calibration will not be performed.

CAL LOCK — This message indicates that the calibration switch (CAL LOCK) is in the disabled position. Calibration will not occur.

It is important to realize that if any of these errors occur, calibration does not occur. When a calibration error occurs, find and fix the problem and repeat calibration.

It is strongly recommended that calibration errors be detected and displayed by the calibration program. The following steps provide the general procedure required to detect calibration errors over the IEEE-488 bus:

1. Program the Model 486/487 to generate an SRQ on an error by sending the U32 command over the bus.
2. When an SRQ occurs (error), send the U1 command and then address the Model 486/487 to talk.
3. Display the character string (U1 Error Status Word) from the Model 486/487on the computer CRT and refer to Figure 4-7 (in Section 4) to determine the type of error.

7.4 HANDLING AND CLEANING PRECAUTIONS

When troubleshooting or otherwise working inside the instrument, care should be taken not to indiscriminately touch PC board traces and open wires to avoid contaminating them with body oils or other foreign matter. Areas covered by the shield within the Model 486/487 have high impedance devices or sensitive circuitry where contamination could cause degraded performance.

The same general precautions apply when replacing parts in these areas. When unsoldering and soldering parts, be careful not to spread the flux around the board to adjacent areas.

1. Using a squeeze bottle, carefully apply clean, uncontaminated methanol to the area to be cleaned. Use sufficient solution to thoroughly wet the circuit board.
2. Using a small, clean brush, wipe the area thoroughly until it is free of flux or contaminants. In some cases, it may be helpful to tilt the board at an angle and brush contaminants away from the affected area, allowing contaminated residue and methanol to run off the board.

3. Wash the area again with fresh, clean methanol, allowing it to drain, flushing contaminants off the board.
4. Once the area is thoroughly cleaned, it should be dried with pressurized dry clean air or nitrogen. Do not use compressed air from an ordinary air compressor, as oil particles in the air could contaminate the circuit board.
5. After cleaning or parts replacement, check to see that any components connected to the Teflon® insulators are not physically touching the board or adjacent parts.

7.5 DISASSEMBLY

The following paragraphs outline the basic procedures for disassembling the Model 486/487. In general, the procedures should be performed in the order presented here. Figure 7-4 shows an exploded view of the instrument that can be used as an aid in disassembling and reassembling the unit.

7.5.1 Cover Removal

WARNING

Disconnect the line cord and all other instruments from the Model 486/487 before removing the case cover.

To remove the cover, remove the rear bezel, then simply remove the bottom screw that secures the cover to the chassis and slide the cover off the chassis to the rear.

To install the cover, slide the cover over the chassis until the front edge is flush with the front panel, then install the screw to secure the cover. Install the rear bezel and secure it.

WARNING

To prevent electric shock, make sure the bottom screw (which grounds the cover to the chassis) is properly installed.

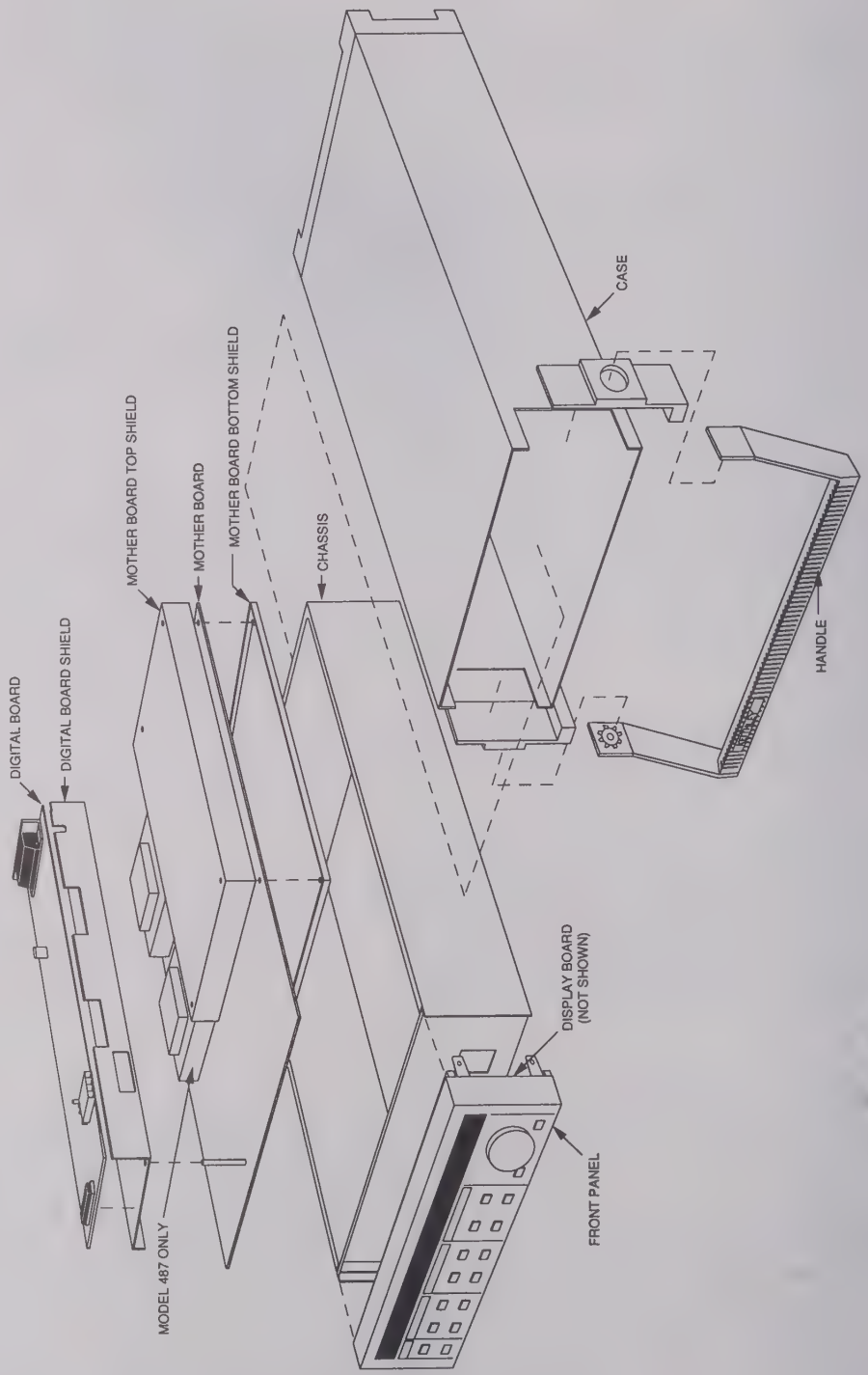


Figure 7-4. Exploded View

7.5.2 Shield Removal

The top and bottom analog shields can be removed as follows:

NOTE
Be careful not to touch critical high-impedance areas of the mother board with your hands after the shields are removed.

1. Remove the four screws that secure the top and bottom shields to the mother board.
2. Remove the bottom shield and set it aside.
3. Carefully guide the top shield forward until it is clear of the rear panel connectors, then lift the shield out of the case.
4. When installing the shields, make sure the insulated gaskets are properly installed on the edges of shields. Each shield has gaskets installed on the two long edges.

7.5.3 Front Panel Removal

Remove the front panel as follows:

1. Disconnect the display board ribbon cable from the digital board.
2. Remove the handle and mounting ears as follows:
   A. Place the handle in its most upright position.
   B. Carefully pull the handle out of its mounting ears located on the side panels of the chassis.
   C. Remove the two mounting ears. Each ear is secured to the chassis with a single screw.
3. Pry the front panel tabs out away from the side panels slightly until the tabs clear the side mounting screw shoulders. As you pry each tab clear, push forward on the front panel so that the tab does not slip back into place.
4. Once all four tabs are clear, slide the front panel forward until it is clear of the chassis.
5. To remove the display board, pull off the knob and unclip the circuit board from the front panel. The board is secured by four snaps.

7.5.4 Circuit Board Removal

Digital Board Removal

1. Disconnect the ribbon cables and the plug for the digital power supply from the digital board.
2. Remove the two screws that secure the digital shield to the side of the case.
3. Remove the two fasteners that secure the IEEE-488 connector to the rear panel.
4. Remove the screw that secures the digital shield to the mother board standoff near the front of the instrument.
5. Remove the board and shield as a unit from the chassis.
6. Remove the screws that secure the digital board to the digital shield, then remove the board.

Mother Board Removal

1. Note the positions of the analog output and V-Source (Model 487) connections, then unplug them from the mother board.
2. Unplug the interlock connector and line power plug from the mother board.
3. Remove the screw that secures the mother board to the front of the chassis.
4. Slide the mother board forward so the slots clear the side tabs.
5. Pull the mother board free of the guide tabs in the side panels, and remove the board.

7.6 SPECIAL HANDLING OF STATIC SENSITIVE DEVICES

CMOS devices operate at very high impedance levels for low power consumption. As a result, any static that builds up on your person or clothing may be sufficient to destroy these devices, if they are not handled properly. Use the following precautions to avoid damaging them.

1. ICs should be transported and handled only in containers specially designed to prevent static build-up. Typically, these parts will be received in anti-static containers of plastic or foam. Keep these devices in their original containers until ready for installation.
2. Remove the devices from their protective containers only at a properly grounded work station. Also, ground yourself with a suitable wrist strap.
3. Handle the devices only by the body; do not touch the pins.

4. Any printed circuit board into which the device is to be inserted must also be grounded to the bench or table.
5. Use only anti-static type solder sucker.
6. Use only grounded tip solder irons.
7. Once the device is installed in the PC board, it is normally adequately protected, and normal handling can resume.

7.7 TROUBLESHOOTING

The troubleshooting information contained in this section is intended for use by qualified personnel having a basic understanding of analog and digital circuitry. The individual should also be experienced at using typical test equipment as well as ordinary troubleshooting procedures. The information here has been written to assist in isolating a defective circuit or circuit section. Isolation of a specific component is left to the technician. Note that schematic diagrams and component location drawings, which are an essential aid to troubleshooting are included in Section 8.

Before starting to troubleshoot the instrument, it is recommended that the theory of operation (Section 6) be studied to familiarize yourself with some of the basic circuit principles.

7.7.1 Recommended Troubleshooting Equipment

Success in troubleshooting complex equipment like the Model 486/487 depends not only on the skill of the technician, but relies on the use of accurate, reliable test equipment. Table 7-4 lists the equipment recommended for troubleshooting the Model 486/487. Other equipment, such as logic analyzers and capacitance checkers, could also be helpful.

7.7.2 Self-Test

The self-test performs tests on the front panel LEDs, as well as the RAM and ROM ICs within the instrument. Perform the self-test as follows:

1. Keep pressing and releasing MENU until the following message is displayed:

   SELFTEST NO

Table 7-4. Recommended Troubleshooting Equipment

Equipment	Description
Keithley Model 199 DMM	Measure AC and DC voltages, and resistances
Keithley Model 263 Current Source	Apply signal currents to input
20MHz oscilloscope	View digital signals, analog waveforms.

2. Use the rotary knob to display the following message:

   SELFTEST YES

3. To begin the self-test, press MENU. The unit will then test the display segments and digits in sequence, and will display the next menu item if the RAM and ROM ICs pass the tests.
4. If a RAM or ROM error occurs during the self-test, the unit will display one of the following messages:

   RAM ERROR

   or

   ROM ERROR

   In this instance, you must press a front panel key to return to return to normal operation.

7.7.3 Analog Control Lines

Control lines on the analog board, managed by the microcomputer, are used to drive the various relays and analog switches associated with analog circuit operation. An appropriate voltage level on a control line will activate the respective relay or analog switch.

Most of the control lines to drive relay coils and inputs of analog switches are located on schematic drawing 486-106 (page 3 for the Model 486) or 487-106 (page 3) for the Model 487.

Control line labels that are terminated with a star (*) indicate that a low logic level (~0V) will activate the relay or switch. For example, 0V present on the control line ZERO

CHECK* indicates that the zero check relay (K110) is activated (closed). The absence of the star (*) in the label indicates that a high logic level (~5V) will activate the relay or switch.

7.7.4 A/D Test Mode

The instrument can be placed in the A/D test mode (DEBUG) which allows the A/D multiplexer (U144) to be stopped in any one of its A/D phases. This feature simplifies signal tracing through the instrument. The three states of the multiplexer (mux) are as follows:

A/D SIG — In this mux state, the amplified and converted input signal is applied to the input of the A/D converter.

A/D ZERO — In this mux state, analog common (0V) is applied to the input of the A/D converter.

A/D REF — In this mux state, the +2.8V reference is applied to the input of the A/D converter.

Perform the following steps to place the instrument in the A/D test mode (DEBUG):

1. Keep pressing and releasing MENU until the following message is displayed:

   DEBUG NO

2. Use the rotary knob to display the following message:

   DEBUG YES

3. Press MENU to place the instrument in the A/D test mode. The multiplexer will stop with the conditioned input signal applied to the input of the A/D converter as indicated by the following message on the right display:

   A/D SIG

4. To select one of the alternate A/D test states, simply use the rotary knob to display one of the following messages:

   A/D ZERO

   or

   A/D REF

5. To exit from the test mode and return the instrument to normal operation, press SHIFT and then EXIT.

7.7.5 Troubleshooting Procedures

Tables 7-5 through 7-8 summarize the troubleshooting procedures for the various circuits within the instrument. In general, the procedures should be performed in the order given. Figure 7-5 shows the various test points for the troubleshooting procedures:

WARNING

Lethal voltages may be present on components and shields. The ac line voltage is present on the pc mother board. Exercise extreme caution when troubleshooting a partially disassembled unit that has power applied to it. Never touch components, shields or the pc boards while power is applied.

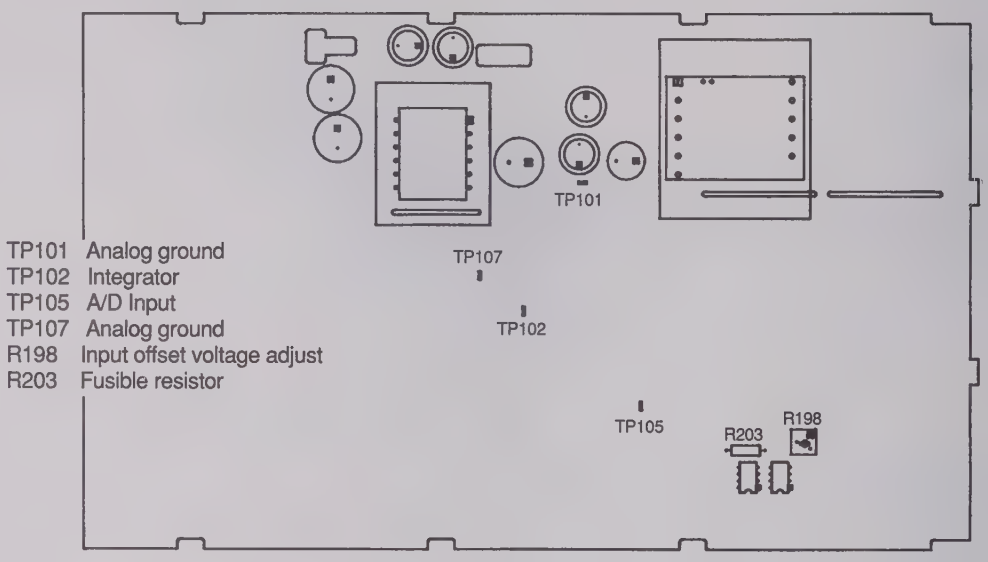


Figure 7-5. Test Point, R198 and R203 Locations

Table 7-5. Power Supply Checks

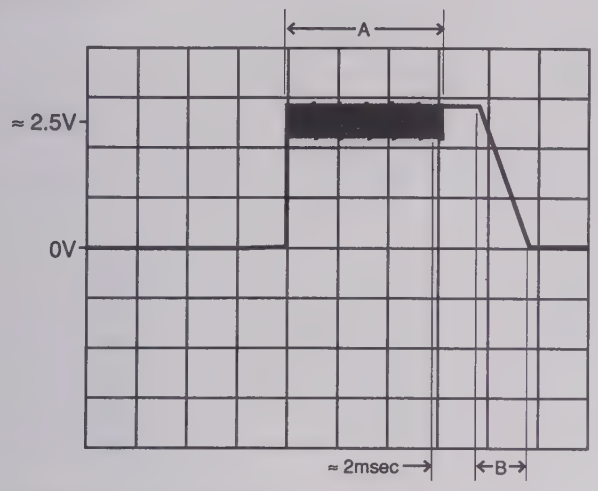
Step	Item/Component	Required Condition	Description
1	S100 line voltage switch	Set to 115 or 230V as required	Line voltage selection
2	F100 line fuse	Check continuity	Remove to check
3	Line power	Plugged into live receptacle, power on	
4	+5V supply (U107, pin 3)	+5V, ±5%	Referenced Analog Ground (TP107)
5	+15V supply, (U106, pin 3)	+15V, ±5%	Referenced Analog Ground (TP107)
6	–15V supply (U108, pin 3)	–15V, ±5%	Referenced Analog Ground (TP107)
7	+6.5V supply (CR109 +)	+6.5V, ±20%	Referenced to digital ground

Table 7-6. Digital Circuitry Checks

Step	Item/Component	Required Condition	Remarks
1	Power on self-test	No failures reported	RAM ERROR: check U511 ROM ERROR: check U508 NO DFLTS: check U510
2	U500, pin 3	+5V, ±5%	+5V digital supply, referenced to digital common (U500, pin 2)
3	U509, pins 34, 35	2MHz square wave	Bus E and Q clocks
4	U509, pin 3	25µsec negative-going pulse every 1msec	MPU $\overline{\text{IRQ}}$ line
5	U509, pin 37	Stays low (≈300msec) on power up, then goes high	MPU $\overline{\text{RESET}}$ line
6	U501, pin 18	1MHz pulse trains	ANALOG CLOCK
7	U501, pin 14	Variable width (increments of 1µsec) pulses.	ANALOG DATA
8	U501, pin 9	Brief pulses	ANALOG STROBE
9	U502, pin 9	56-pulse burst at 1msec intervals	DISPLAY CLOCK
10	U501, pin 3	Pulse burst every 1msec	DISPLAY DATA
11	U501, pin 7	Positive pulse every 1msec	DISPLAY LEFT signal
12	U502, pin 3	Positive pulse every 1msec	DISPLAY RIGHT signal
13	U504, pin 4	Pulse train with ZERO CHECK pressed	KEY S0 data
14	U504, pin 5	Pulse train with LOCAL pressed	KEY S1 data
15	U504, pin 6	Pulse train with FILTER pressed	KEY S2 data
16	U503, pin 6	Negative-going pulses every 1msec	SHIFT DONE signal
17	U505, pins 2, 3	Alternates between high and low every other knob click	Knob data
18	U515, pin 8	Goes low when bus command is sent	IEEE-488 ATN line
19	U515, pins 4, 5, 6	Refer to Figure E-2 for required conditions	Handshake sequence for NDAC, NRFD, and DAV

Table 7-7. Analog Circuitry Checks

Step	Item/Component	Required Condition	Remarks
1	Front panel controls	Range: Auto; Filter: Enabled (Analog+Digital); Zero Check: Enabled	Initial conditions
2	Reference point	Connect DMM LO or scope LO to analog common (Input low)	All voltages referenced to analog common
3	Zero correct	Press SHIFT CORRECT	Zero correct unit
4	U142, pin 6	0V ±1mV	Input op amp output
5	U146, pin 6	0V ±1mV	Input filter output
6	ANALOG OUTPUT	0V ±1mV	Instrument output
7	INPUT jack	Apply +1.00000mA and disable zero check	Positive current input
8	U142, pin 6	–1.2V	Input op amp output
9	U146, pin 6	–1V	Input amplifier output
10	ANALOG OUTPUT	+1V	Instrument output
11	INPUT jack	Apply –1.00000mA	Negative current input
12	U142, pin 6	+1.2V	Input op amp output
13	U146, pin 6	+1V	Input amplifier output
14	ANALOG OUTPUT	–1V	Instrument output
15	Repeat steps 7-14 for listed inputs	Input ±100.000µA ±10.0000µA ±1.00000µA ±100.000nA ±10.0000nA ±1.00000nA	All measured voltages should be ±1V at: U142, pin 6 U146, pin 6 ANALOG OUTPUT
16	INPUT jack	Apply +1.00000mA	
17	A/D test mode (DEBUG)	Place unit in A/D REF test mode (see paragraph 7.7.4)	Mux set at REF
18	TP105	+2.8V	Mux at REF
19	A/D Test mode (DEBUG)	Place unit in A/D ZERO test mode	
20	TP105	0V	Mux at ZERO
21	A/D test mode (DEBUG)	Place unit in A/D SIG test mode	
22	TP105	–1V	Mux at SIGNAL
23	Normal operation	Exit A/D test mode	
24	TP102	See Figure 7-6	Integration output
25	U129, pin 13	Variable pulse train (0V to 5V)	A/D counts



A : Fast Integration = 1.6msec
60Hz Integration = 16.6msec
50Hz Integration = 20msec

B : Fast Integration ≅ 1msec
50,60Hz Integration ≅ 3msec

Figure 7-6. Integrator Output (Typical)

Table 7-8. V-Source Checks (Model 487 Only)

Step	Item/Component	Required Condition	Remarks
1	V-Source Controls	Standby operation 00.000V setting (50V range)	Initial conditions
2	Reference point	Connect DMM LO on scope LO to V-SOURCE OUTPUT LO	All voltages referenced to V-Source common.
3	U100, pin 1	+15V, ±5%	+15VB supply
4	U101, pin 3	–15V, ±5%	–15VB supply
5	U102, pin 1	+5V, ±5%	+5VB supply
6	VR100, anode	+800V, ±15%	+800VB supply
7	V-Source Controls	Set to 10.000V (50V range) Place in OPERATE	Source +10V on 50V range to open output terminals
8	U151, pin 5	+1.54V	DAC output
9	U143, pin 6	–1.54V	Inverting X1 buffer output
10	U110, pin 6	–7V	High impedance amplifier output
11	Q101, gate	+13V	Power FET
12	Q105, source	–3V	Power FET
13	V-Source Output	+10.000V ±14mV	Voltage source output
14	V-Source Controls	Set to 010.00V (500V range). Place in OPERATE	Source +10V on 500V range
15	U151, pin 5	+153mV	DAC output
16	U143, pin 6	–153mV	Inverting X1 buffer output
17	U110, pin 6	–7V	High impedance amplifier output
18	Q101, gate	+13V	Power FET
19	Q105, source	–3V	Power FET
20	V-Source Output	+10.000V, ±55mV	Voltage source output
21	—	Short output, set I-Limit to 2.5mA	—
22	Q103, source	+0.7V	Power FET
23	—	Set I-Limit to 25µA	—
24	U119, pin 6	–9V	25µA I-Limit control
25	VR106, cathode	–3V	Line voltage protection
26	Q101, gate	+3V	Power FET
27	Q105, source	–3V	Power FET
28	V-Source Controls	Place in Standby	

7.7.6 Input Offset Voltage Adjust

If the input amplifier op amp, or a component in the offset voltage adjust circuit is replaced, a course adjustment to cancel input offset voltage will have to be performed. Replacing any of the following components will require the pot adjustment to be made: U142, R191, R195, R198, R220, and R215.

Perform the following steps to adjust offset voltage:

1. Turn on the instrument and allow it to warm up for two hours.
2. Configure the Model 486/487 as follows: Zero check disabled and the 2mA range selected.
3. Connect the Model 197 DMM across the input and select the 200mV range.
4. Using a small bladed screwdriver, adjust pot R198 for a display reading of less than 50μV on the Model 197.

7.7.7 Fusible Resistor Replacement

A fusible resistor (R203) is used to protect the analog output circuitry.

CAUTION

To prevent damage to the instrument, adhere to the following precautions when floating the input above chassis ground:

1. Do not connect ANALOG OUTPUT LO to CHASSIS. If there is a ground link installed at the rear panel binding posts, remove it.
2. Make sure that any monitoring instrument connected to the analog output is floating.

Paragraph 3.16.8 explains the precautions for floating measurements in more detail.

In the event that the fusible resistor (R203) becomes damaged, replace it with the the following type:

Circuit Desig.	Description	Keithley Part No.
R203	Fusible Resistor, 1kΩ, 1/2W, 1%, Metal Film	R-370-1K

SECTION 8
Replaceable Parts

8.1 INTRODUCTION

This section contains replacement parts information, component location drawings and schematic diagrams for the Models 486 and 487.

8.2 PARTS LISTS

Parts are listed alphanumerically in order of their circuit designations. The first two parts lists contain information for the display boards of the Models 486 and 487. The next parts list contains information for the digital boards of both the Models 486 and 487. The next two parts lists contain information for the analog boards of the instruments. The last two parts lists contain information on miscellaneous parts that do not pertain to any of the pc boards.

8.3 ORDERING INFORMATION

To place an order, or to obtain information concerning replacement parts, contact your Keithley representative or the factory. See inside front cover for addresses. When ordering, include the following information:

1. Instrument Model Number
2. Instrument Serial Number
3. Parts Description
4. Circuit Designation (if applicable)
5. Keithley Part Number

If an additional instruction manual is required, order the manual package (Keithley Part Number 486-901-00). The manual package will contain an instruction manual and any applicable addenda.

8.4 FACTORY SERVICE

If the instrument is to be returned to the factory for service, please complete the service form which follows this section and return it with the instrument.

8.5 SCHEMATIC DIAGRAMS AND COMPONENT LOCATION DRAWINGS

Schematic diagrams and component location drawings follow the appropriate replaceable parts list for that particular board.

MODEL 486 DISPLAY BOARD, PARTS LIST

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
	BUMPER	FE-23A
	BUSHING, KNOB	428-314A
	CLIP,GROUND	428-324A
C400..402, 405..410	CAP,.01UF,20%,50V,CERAMIC	C-365-.01
C403	CAP, 10UF,-20+100%,25V,ALUM ELEC	C-314-10
DS400..DS409	DIGITAL DISPLAY	DD-46
DS410	DISPLAY ALPHANUMERIC	DD-45
DS411..DS415	PILOT LIGHT, RED,LED	PL-83
P1007	CABLE ASSEMBLY, 20 CONDUCTOR	CA-27-9B
R400	RES,1.47K,1%,1/8W,METAL FILM	R-88-1.47K
R401..404	RES NET, 82, 2%,.2W	TF-223-82
R405,R406	RES NET,82,2%,.25W	TF-141
R407,R408	RES NET, 120, 2%,.25W	TF-221-120
S400,401,408, 411,414,415	SWITCH, MOMENTARY	SW-481
S402..405,409, 410,412	SWITCH, MOMENTARY W/LED, HIGH EFF.,RED	SW-482
S407	SWITCH, ENCODER, DIG 2-BIT GRAY CODE	SW-480
U401,U408, U409,U412	IC,8-BIT SERIAL-INPUT,UNC5895A	IC-537
U404	IC,8-BIT SERIAL-INPUT,UNC5821A	IC-684
U405,U410	IC,8-CHANNEL SAT SINK DRIVER,UDN-2596A	IC-578
U406,U411	IC,8-STAGE SHIFT/STORE REG,74HCT4094	IC-691
	USED WITH DS400..DS409	
	SOCKET, CARRIER	428-320A
	USED WITH DS410	
	SOCKET	SO-127-1
	USED WITH DS411..DS415	
	MOUNTING KIT	MK-22-4

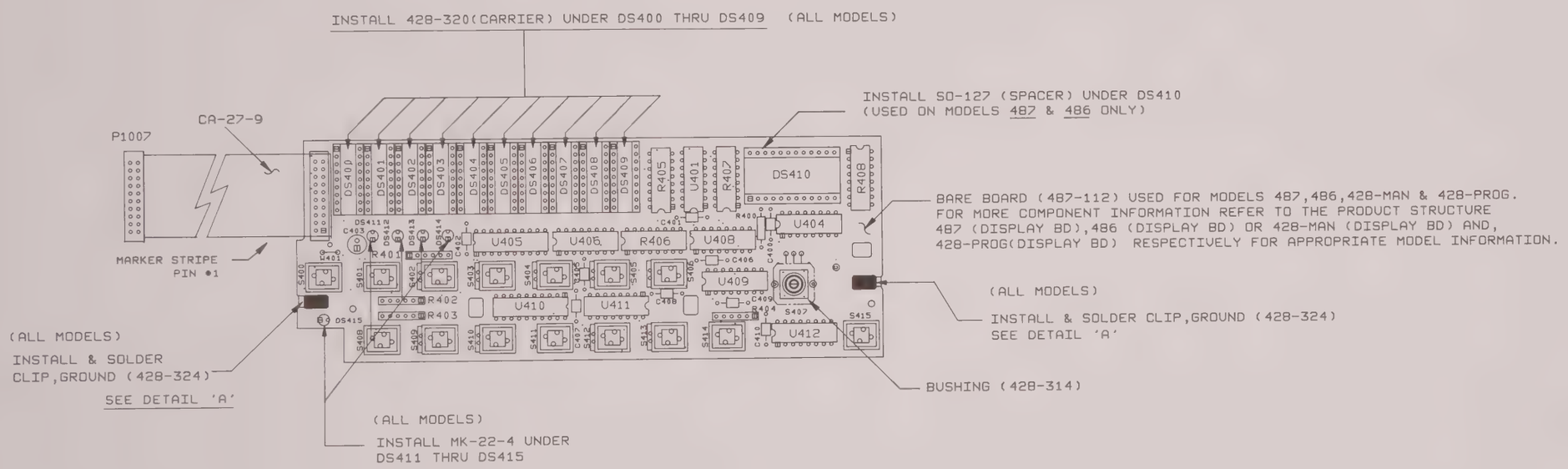
MODEL 487 DISPLAY BOARD, PARTS LIST

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
	BUMPER	FE-23A
	BUSHING, KNOB	428-314A
	CLIP,GROUND	428-324A
C400..402, 405..410	CAP,.01UF,20%,50V,CERAMIC	C-365-.01
C403	CAP, 10UF,-20+100%,25V,ALUM ELEC	C-314-10
DS400..409	DIGITAL DISPLAY	DD-46
DS410	DISPLAY ALPHANUMERIC	DD-45
DS411..415	PILOT LIGHT, RED,LED	PL-83
P1007	CABLE ASSEMBLY, 20 CONDUCTOR	CA-27-9B
R400	RES,1.47K,1%,1/8W,METAL FILM	R-88-1.47K
R401..404	RES NET, 82, 2%,.2W	TF-223-82
R405,406	RES NET,82,2%,.25W	TF-141
R407,408	RES NET, 120, 2%,.25W	TF-221-120
S400,401,408, 411,414,415	SWITCH, MOMENTARY	SW-481
S402..406,409, 410,412,413	SWITCH, MOMENTARY W/LED, HIGH EFF.,RED	SW-482
S407	SWITCH, ENCODER, DIG 2-BIT GRAY CODE	SW-480
U401,408,409, 412	IC,8-BIT SERIAL-INPUT,UNC5895A	IC-537
U404	IC,8-BIT SERIAL-INPUT,UNC5821A	IC-684
U405,410	IC,8-CHANNEL SAT SINK DRIVER,UDN-2596A	IC-578
U406,U411	IC,8-STAGE SHIFT/STORE REG,74HCT4094	IC-691
	USED WITH DS400..DS409	
	SOCKET, CARRIER	428-320A
	USED WITH DS410	
	SOCKET	SO-127-1
	USED WITH DS411..415	
	MOUNTING KIT	MK-22-4

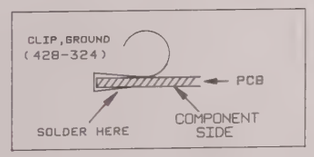
NO. 487-110-*

LTR.	ECO NO.	REVISION	ENG.	DATE
B	891026	RELEASED	MS	10/26/89
B1	13826	DELETED C404 & ADDED W401.		02/26/90

MODEL 487 (487-110-01) AS SHOWN



DETAIL 'A'



MODEL 486 (487-110-03)

1. TO GENERATE THE MODEL 486 DISPLAY BOARD (487-110-03) DELETE THE FOLLOWING COMPONENTS (487-110-01).

S406,S413

2. REFER TO PRODUCT STRUCTURE 486(DISPLAY BD) FOR COMPLETE COMPONENT INFO.

MODEL'S 428-MAN & 428-PROG. (487-110-02)

1. TO GENERATE THE MODEL 428 DISPLAY BOARDS (487-110-02) DELETE THE FOLLOWING COMPONENTS (487-110-01).

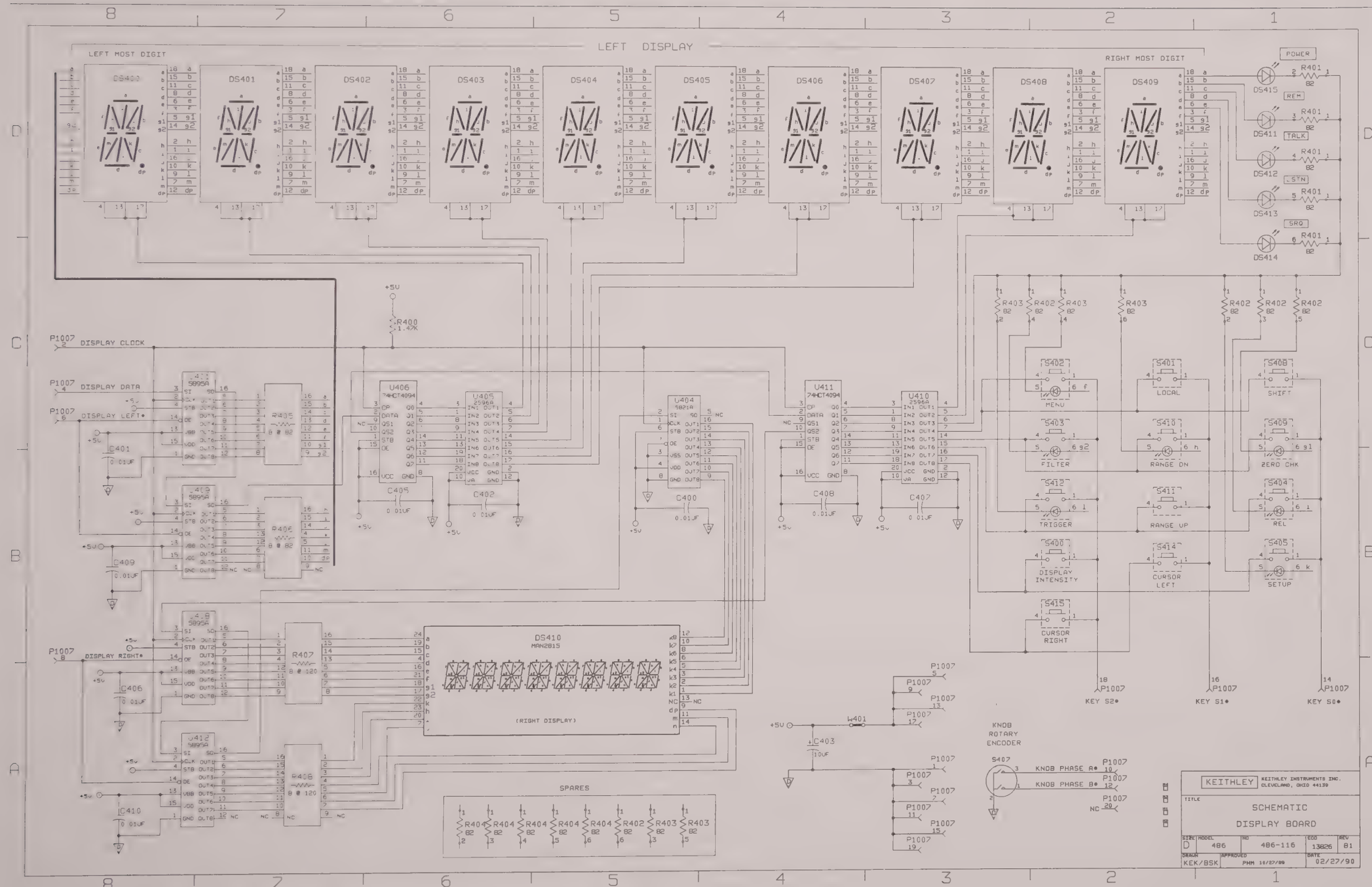
C400,C406,C410
DS410 & SO-127
U408,U412,U404,
R407,R408

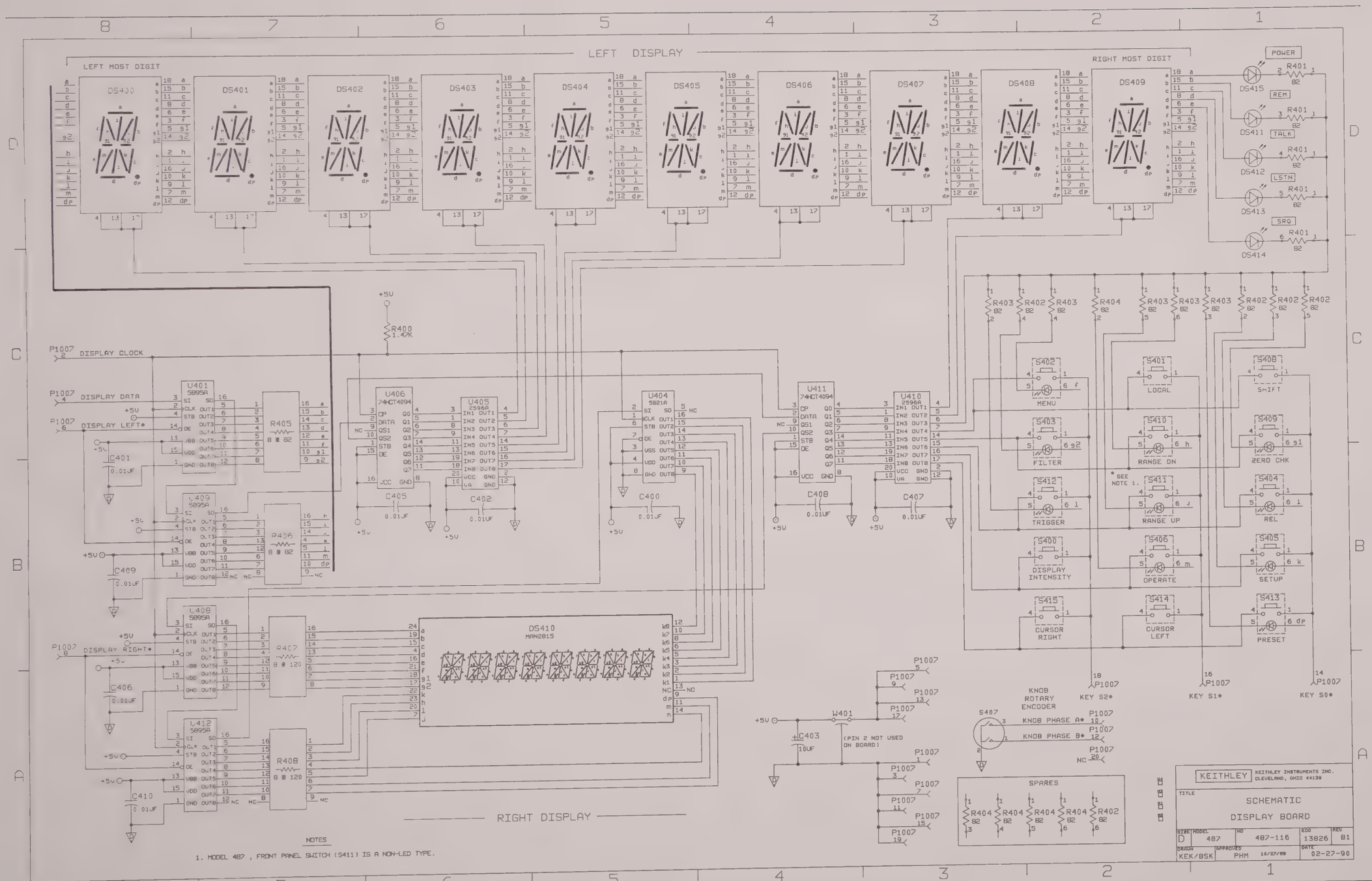
2. REPLACE S411 (SW-481), WITH A (SW-482).

3. REFER TO PRODUCT STRUCTURE 428-MAN (DISPLAY BD) AND 428-PROG (DISPLAY BD) FOR COMPLETE COMPONENT INFORMATION.

MODEL	NEXT ASSEMBLY	QTY.
	USED ON	
428-PROG		1
428-MAN		1
486		1
487		1

DO NOT SCALE THIS DRAWING	DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED	DATE 8-16-89	SCALE 1:1	TITLE COMPONENT LAYOUT, DISPLAY BOARD
KEITHLEY KEITHLEY INSTRUMENTS INC. CLEVELAND, OHIO 44139	XX=±.015 ANG.=±1°	DRN. BSK	ENG. APPR.	
	XXX=±.005 FRAC.=±1/64	MATERIAL NONE	C	NO. 487-110-*
	SURFACE MAX. 63	FINISH NONE		


LEFT DISPLAY
LEFT MOST DIGIT
RIGHT MOST DIGIT
DS400
DS401
DS402
DS403
DS404
DS405
DS406
DS407
DS408
DS409
POWER
REM
TALK
LSTN
SRQ
DS415
DS411
DS412
DS413
DS414
R401
82
+5V
R400
1.47K
P1007
DISPLAY CLOCK
DISPLAY DATA
DISPLAY LEFT*
DISPLAY RIGHT*
U406
74HCT4094
U405
2596A
U404
5821A
U411
74HCT4094
U410
2596A
C405
C402
C400
C408
C407
C401
C409
C406
C410
0.01UF
R405
R406
R407
R408
8 @ 82
8 @ 120
DS410
MAN2815
(RIGHT DISPLAY)
SPARES
R404
R403
R402
S402
MENU
S401
LOCAL
S408
SHIFT
S403
FILTER
S410
RANGE DN
S409
ZERO CHK
S412
TRIGGER
S411
RANGE UP
S404
REL
S400
DISPLAY INTENSITY
S414
CURSOR LEFT
S405
SETUP
S415
CURSOR RIGHT
KEY S2*
KEY S1*
KEY S0*
W401
C403
10UF
KNOB ROTARY ENCODER
S407
KNOB PHASE A*
KNOB PHASE B*
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
TITLE
SCHEMATIC
DISPLAY BOARD
SIZE D
MODEL 486
NO 486-116
ECO 13826
REV B1
DRAWN KEK/BSK
APPROVED PHM 10/27/89
DATE 02/27/90


LEFT DISPLAY
RIGHT DISPLAY
LEFT MOST DIGIT
RIGHT MOST DIGIT
DS400
DS401
DS402
DS403
DS404
DS405
DS406
DS407
DS408
DS409
DS410
MAN2815
DS411
DS412
DS413
DS414
DS415
POWER
REM
TALK
LSTN
SRQ
R400
1.47K
R401
R402
R403
R404
R405
R406
R407
R408
82
120
P1007
DISPLAY CLOCK
DISPLAY DATA
DISPLAY LEFT*
DISPLAY RIGHT*
+5V
U401
U402
U403
U404
U405
U406
U407
U408
U409
U410
U411
U412
5895A
5821A
2596A
74HCT4094
C400
C401
C402
C403
C405
C406
C407
C408
C409
C410
0.01UF
10UF
W401
(PIN 2 NOT USED ON BOARD)
S400
S401
S402
S403
S404
S405
S406
S407
S408
S409
S410
S411
S412
S413
S414
S415
MENU
FILTER
TRIGGER
DISPLAY INTENSITY
CURSOR RIGHT
LOCAL
RANGE DN
RANGE UP
OPERATE
CURSOR LEFT
SHIFT
ZERO CHK
REL
SETUP
PRESET
SEE NOTE 1.
KNOB ROTARY ENCODER
KNOB PHASE A*
KNOB PHASE B*
KEY S2*
KEY S1*
KEY S0*
SPARES
NOTES
1. MODEL 487 , FRONT PANEL SWITCH (S411) IS A NON-LED TYPE.
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
TITLE
SCHEMATIC
DISPLAY BOARD
SIZE D
MODEL 487
NO 487-116
ECO 13826
REV B1
DRAWN KEK/BSK
APPROVED PHM 10/27/89
DATE 02-27-90

MODELS 486 AND 487 DIGITAL BOARD, PARTS LIST

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
C500	CAP, 0.47UF,20%,50V CERAMIC	C-237-.47
C501	CAP,47UF,-20+100%,25V,ALUM ELEC	C-314-47
C502..509,512, 513,516..519	CAP,.01UF,20%,50V,CERAMIC	C-365-.01
C510,511	CAP,15PF,10%,200V,CERAMIC	C-406-15P
C514	CAP,.1UF,20%,50V,CERAMIC	C-365-.1
C515	CAP,10UF,10%,20V,TANTALUM ELECTROLYTE	C-204-10
CR500..503	DIODE,SILICON,IN4148 (DO-35)	RF-28
J1003	CONN,RIGHT ANGLE,24 PIN	CS-501
J1005,J1007	CONN,HEADER STRAIGHT SOLDER PIN	CS-368-20
J1006	CONNECTOR, HEADER	CS-715-4
R500,R501	RES,18K,5%,1/4W,COMPOSITION OR FILM	R-76-18K
R502	RES NET, 3.3K,2%,.6W	TF-101
R503,R507	RES NET,3.3K,5%,1.25W	TF-140
R504,R506	RES,100,5%,1/4W,COMPOSITION OR FILM	R-76-100
R505	RES,3.3K,5%,1/4W, COMPOSITION OR FILM	R-76-3.3K
R508,R509	RES NET,3.3K,2%,.25W	TF-77
U500	IC,+5V VOLTAGE REGULATOR,LM2940CT	IC-576
U501,U502	IC,OCTAL TRI STATE BUFFER,74HCT240	IC-683
U503	IC,DUAL 4 BIT COUNTER,74HCT393	IC-462
U504	IC,VERSATILE INTERFACE ADAPTER,G65SC22	LSI-86
U505	IC,DUAL D FLIP FLOP W/SET & RESE,74HCT74	IC-515
U506	IC,8-BIT PARALLEL TO SERIAL,74HCT165	IC-548
U507	IC, AND-OR-INVERT ARRAY,PAL16L8H-15	IC-687A
U508	EPROM PROGRAM	487-800-*
U509	IC,8 BIT MICROPROCESSING UNIT,MC68B09	LSI-65
U510	IC,PROGRAMMABLE E2ROM 2816B	LSI-83
U511	IC,(8KX8)HI SPEED STATIC CMOS RAM,6264	LSI-66
U512	IC,QUAD 2-INPUT NOR GATE,74HCT02	IC-510
U513	IC,SUPPLY VOLTAGE SUPERVISOR,TL7705AC	IC-602
U514	IC,GPIB ADAPTER,9914A	LSI-49
U515	IC,OCTAL INTERFACE BUS TRANSCEIVER,75161	IC-299
U516	IC,OCTAL INTERFACE BUS,75160	IC-298
	USED WITH U508,U511	
	SOCKET,I.C. 28 PIN	SO-69
W501	JUMPER	J-15
Y500	CRYSTAL,8.0000MHZ	CR-24-1

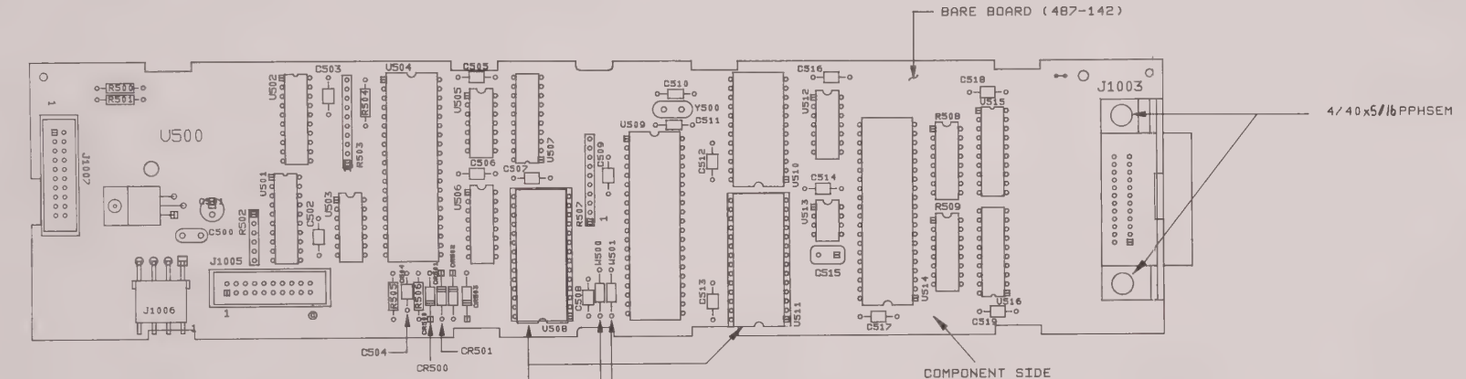
*ORDER CURRENT FIRMWARE REVISION LEVEL.

NO. 487-140-*

LTR.	ECO NO.	REVISION	ENG.	DATE
B	891031	RELEASED		10-31-89
C	13818	REVISED		12-10-89

MODEL'S 487, 486 & 428-PROG. (487-140-01) AS SHOWN

REFER TO 487 (DIGITAL BD.), 486 (DIGITAL BD.) & 428-PROG. (DIGITAL BD.) PRODUCT STRUCTURE FOR COMPLETE COMPONENT INFORMATION.



(ALL MODELS)
ATTACH SO-69 SOCKET
BEFORE INSTALLING PROGRAMMED LSI-*
(SEE TABLE 1) AND U511 (LSI-66.)

INSTALL JUMPER (J-15)
IN POSITION (W501) FOR MODEL'S
487 & 486 (REFER TO TABLE 1.)

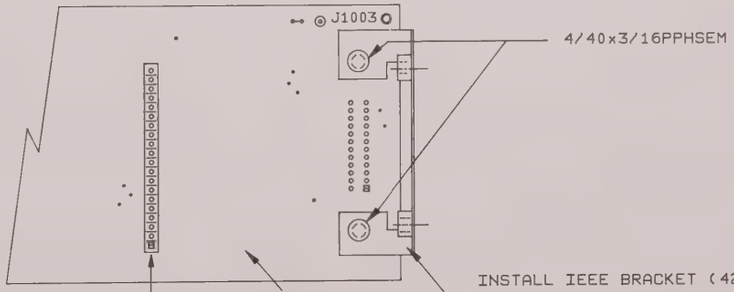
INSTALL JUMPER (J-15)
IN POSITION (W500) FOR MODEL'S
428-MAN. & 428-PROG. (REFER TO TABLE 1.)

TABLE 1.

JUMPER AND FIRMWARE SELECTION TABLE

JUMPER POSITION				PROGRAMMED LSI-*
MODEL	ASSEMBLY	W500	W501	U508
428-MAN.	487-140-02	IN	OUT	428-800
428-PROG.	487-140-01	IN	OUT	428-800
486	487-140-01	OUT	IN	487-800
487	487-140-01	OUT	IN	487-800

DETAIL 'A
428-MAN (487-140-02)



INSTALL IEEE BRACKET (428-321) AS SHOWN.
(REPLACES (CS-501)

INSTALL & SOLDER CONNECTOR (CS-339-20
IN HOLES (1 THRU 20) OF U514 (REMOVED).
(CONNECTOR USED FOR AUTOMATED TEST)

MODEL 428-MAN. COMPONENT LAYOUT (487-140-02)

1. TO GENERATE MODEL 428-MAN, DIGITAL BD., DELETE THE FOLLOWING COMPONENTS:

C517 THRU C519
J1003 (CS-501) IEEE CONNECTOR) & REPLACE WITH 428-321 (IEEE BRACKET) SEE DETAIL 'A
R508 & R509
U516, U515 & U514

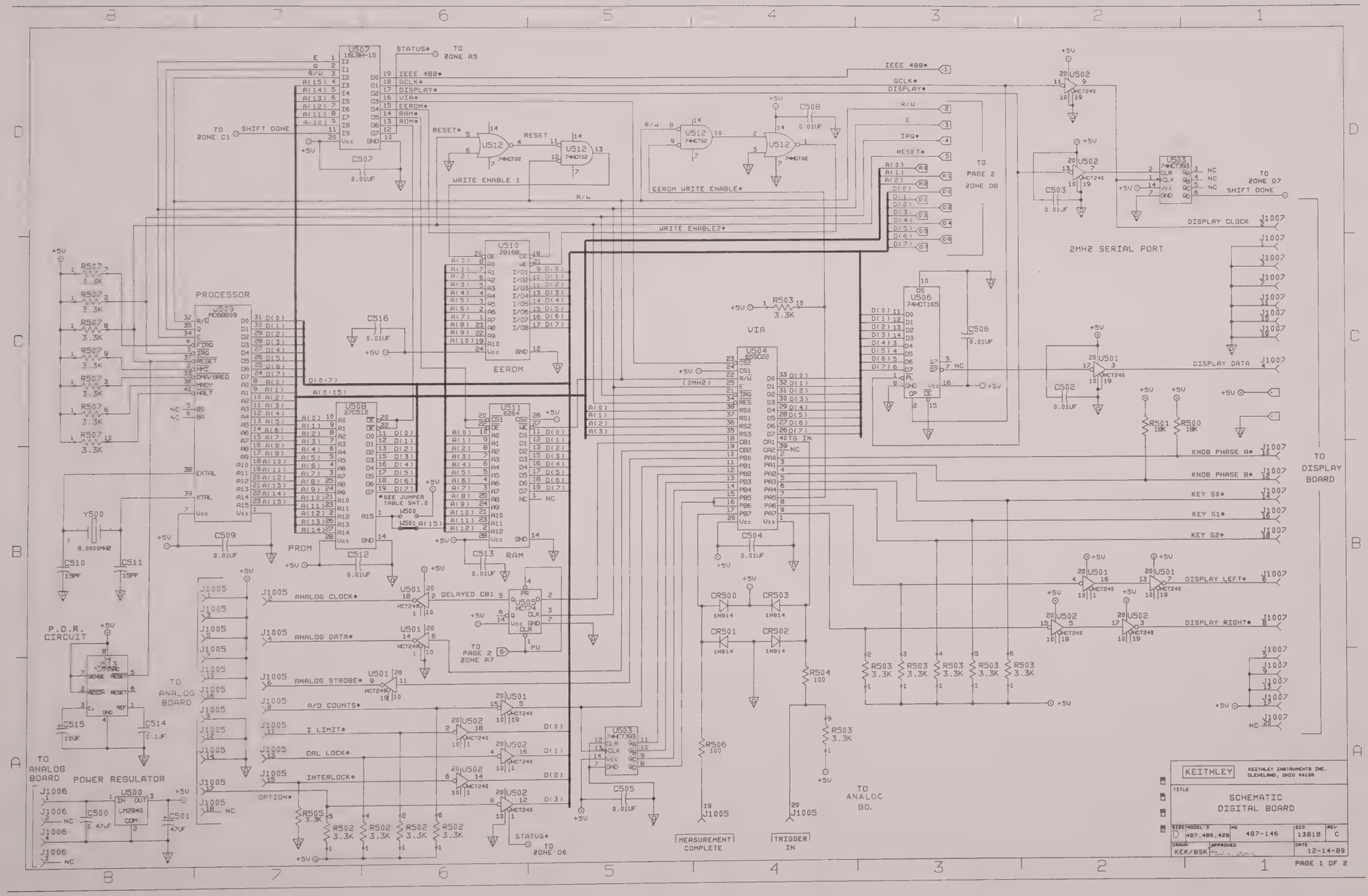
2.

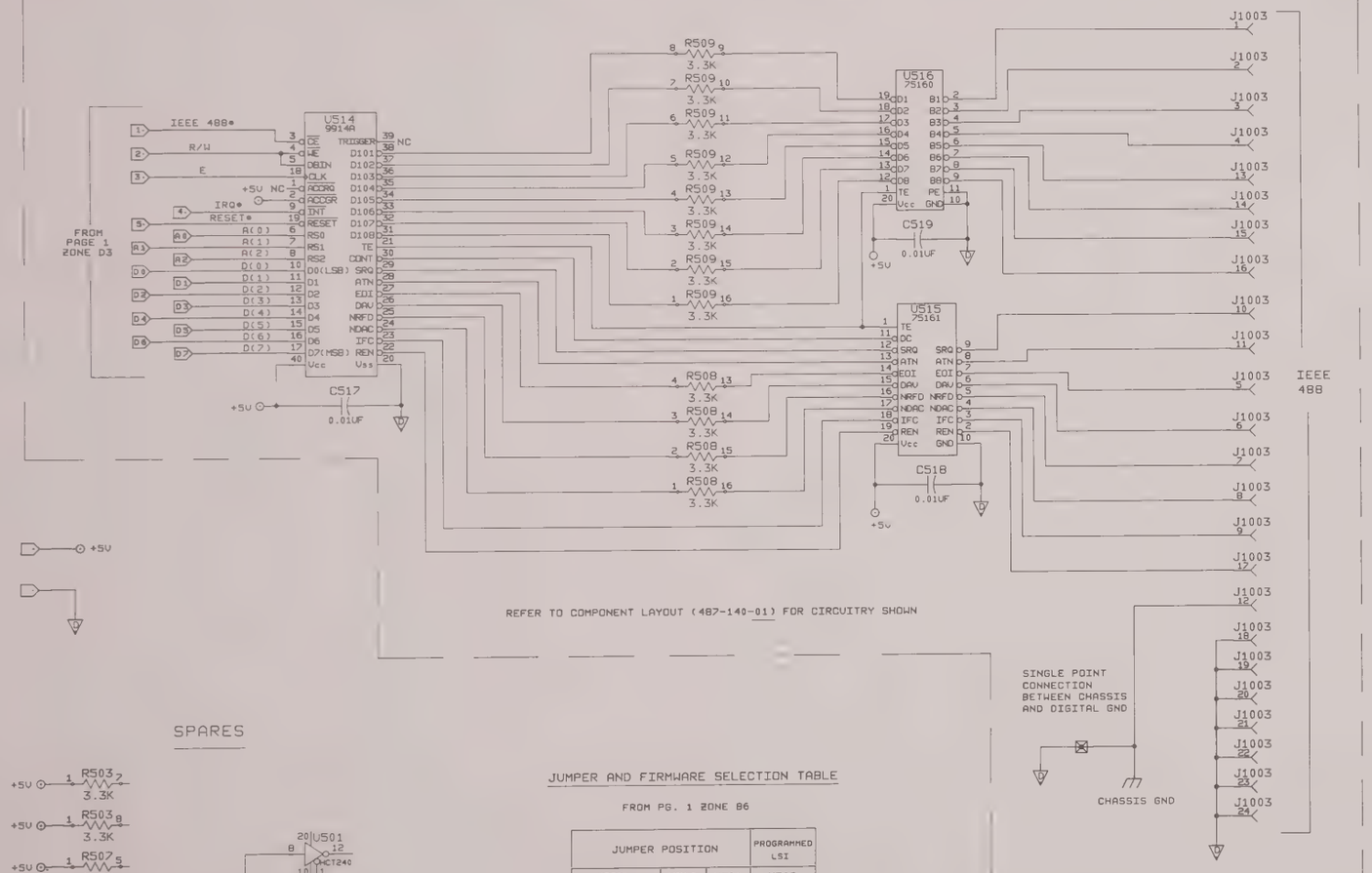
INSTALL & SOLDER CS-339-20 INTO HOLES (1 - 20) OF U514 SEE DETAIL 'A
INSTALL JUMPER (J-15) IN POSITION W500 (SEE TABLE 1.)
INSTALL U508 (PROGRAMMED P/N 428-800) INTO SOCKET (SO-69) (SEE TABLE 1.)

3. REFER TO 428-MAN (DIGITAL BD) PRODUCT STRUCTURE FOR COMPLETE COMPONENT INFORMATION.

MODEL	NEXT ASSEMBLY	QTY. USED ON
428-MAN.	487-140-02	1
428-PROG.	487-140-01	1
486	487-140-01	1
487	487-140-01	1

DO NOT SCALE THIS DRAWING	DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED	DATE 9-06-89	SCALE 1:1	TITLE COMPONENT LAYOUT, DIGITAL BOARD
KEITHLEY KEITHLEY INSTRUMENTS INC. CLEVELAND, OHIO 44139	XX=±.015 ANG.=±1°	DRN. BSK	ENG. APPR.	
	XXX=±.005 FRAC.=±1/64	MATERIAL NONE		C NO. 487-140-*
	SURFACE MAX. 63	FINISH NONE		

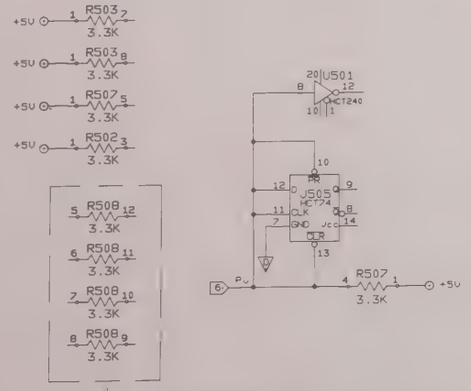

PROCESSOR
EEROM
PROM
RAM
VIA
2MHZ SERIAL PORT
P.O.R. CIRCUIT
POWER REGULATOR
TO ANALOG BOARD
TO DISPLAY BOARD
TO ANALOG BD.
SCHEMATIC DIGITAL BOARD
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
487-146
13818
12-14-89
PAGE 1 OF 2



IEEE OPTION

CIRCUITRY SHOWN NOT PRESENT ON MODEL 428-MAN (487-140-02)

SPARES



PARTS INDICATED ARE PART OF IEEE OPTION AND ARE NOT PRESENT ON MODEL 428-MAN.

JUMPER AND FIRMWARE SELECTION TABLE

FROM PG. 1 ZONE B6

JUMPER POSITION			PROGRAMMED LSI
MODEL	W500	W501	U508
428-MAN	IN	OUT	428-B00
428-PROG.	IN	OUT	428-B00
486	OUT	IN	487-B00
487	OUT	IN	487-B00

KEITHLEY — KEITHLEY INSTRUMENTS INC. CLEVELAND, OHIO 44139

TITLE: SCHEMATIC DIGITAL BOARD

SIZE	MODEL'S	NO	ECO	REV
D	487,486,428	487-146	13818	C

DRAWN	APPROVED	DATE
KEK/BSK		12-14-89

KEITHLEY **REGISTRATION CARD:** Please return. This is the only way we can contact you directly on revisions, upgrades, etc.

MODEL _____ Serial Number _____ Date _____

NAME

COMPANY DIV/DEPT BLDG MS

STREET ADDRESS

CITY STATE/PROVINCE ZIP CODE COUNTRY

( ) _____

PHONE (PLEASE PRINT)

For **FREE** additional information check below:

☐ Application Notes

☐ Programming Guides

TYPE OF FACILITY: Check one.

- ☐ F Education / University
- ☐ G Test / Measurement Equip. Mfg.
- ☐ J Semiconductor Mfg. – Commercial
- ☐ L Semiconductor Mfg. – Captive
- ☐ H Components Mfg. (resistors, capacitors, etc.)
- ☐ K Aerospace / Defense
- ☐ M Utility
- ☐ N Computer / Peripheral Mfg.
- ☐ P Communications Equip. Mfg.
- ☐ B Industrial Controls Mfg.
- ☐ Q Chem. / Petroleum Processing
- ☐ I Other Processing
- ☐ E Research Labs
- ☐ R Medical Equip. and Services
- ☐ S Automotive / Parts Mfg.
- ☐ Z Office Equipment Mfg.
- ☐ T Consumer Electronics Mfg.
- ☐ X Other: _____
- ☐ C We are authorized to use the GSA contract.

We now use Keithley instrument model(s):

_____

DEPARTMENT: Check one.

- ☐ 2 Research or Education
- ☐ 3 Design
- ☐ 4 Calibration Lab/Instrument Pool
- ☐ 5 Production Test
- ☐ 6 Component Test
- ☐ 8 Quality Assurance / Control
- ☐ 0 Purchasing
- ☐ X Other: _____

PRODUCT INTEREST(S)

- ☐ 0 Temperature Measurements
- ☐ 1 Bench DMMs
- ☐ 2 System DMMs
- ☐ 4 Electrometers/Picoammeters
- ☐ 5 Nanovoltmeters
- ☐ 6 Resistance Meas. Instruments
- ☐ 7 Current / Voltage Sources
- ☐ L Calibration Sources
- ☐ V CV Meters
- ☐ I IV Characterization
- ☐ S Switching Systems / Scanners (1-, 2-, 4-pole, and matrix)
- ☐ X Other: _____

HAVE YOU USED KEITHLEY INSTRUMENTS IN THE PAST?

☐ Yes: (which ones) _____ ☐ No

PURCHASED THIS UNIT.

☐ From a Keithley Representative ☐ Direct from Keithley

(OVER)

MODEL 486 ANALOG BOARD, PARTS LIST

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
	PUSHBUTTON	31470-2B
	CONN,BERG	CS-339
	STANDOFF	ST-139-18
	CONNECTOR	CS-276
	HEAT SINK	HS-41
	STANDOFF	ST-195-2
	FUSE HOLDER	FH-21
	FUSE CARRIER	FH-25
C108,114	CAP,2200,20%,35V,ALUM ELECTROLY	C-428-2200
C115	CAP,10,000UF,-20+100%,16V ALUMINUM	C-313-10000
C117	CAP,1500UF,-20,+100%,25V,ALUM ELEC	C-314-1500
C118,120,124, 198,195,196	CAP,.1UF,20%,50V,CERAMIC	C-237-.1
C119,127.130 134,138,140, 199.207, 209.215,217	CAP,.1UF,20%,50V,CERAMIC	C-365-.1
C121..123	CAP, 10UF,-20+100%,25V,ALUM ELEC	C-314-10
C126	CAP,.01UF,10%,1000V,CERAMIC	C-64-.01
C131,171	CAP,330PF,10%,1000V,CERAMIC	C-64-330P
C132	CAP,22PF,20%,500V,CERAMIC	C-22-22P
C133	CAP,820PF,10%,1000V,CERAMIC	C-64-820P
C135,172,177	CAP,100PF,10%,1000V,CERAMIC	C-64-100P
C136,143	CAP,1UF,20%,50V, CERAMIC	C-237-1
C137	CAP,.0033,20%,500V, CERAMIC	C-22-.0033
C141	CAP,.0047UF,10%,100V,POLYPROPYLENE	C-306-.0047
C145,147	CAP,22PF,10%,1000V,CERAMIC	C-64-22P
C148,159	CAP,10PF,10%,1000V,CERAMIC	C-64-10P
C155	CAP,710PF,2%,50V,CERAMIC	C-348-710P
C158	CAP,3.3PF,.5%,1000V,CERAMIC	C-308-3.3P
C169	CAP,150PF,10%,1000V,CERAMIC	C-64-150P
C173	CAP,47PF,10%,1000V,CERAMIC	C-64-47P
C190	CAP,.68,.20%,50V POLYESTER	C-344-.68
C191	CAP,.33,.20%,50V POLYESTER	C-344-.33
CR106,108	DIODE,SILICON,W04M (CASE WM)	RF-46
CR109	DIODE, BRIDGE PE05	RF-48
CR117	DIODE,BRIDGE,VM18	RF-52
F100	FUSE .5A,250V,3AG, SLO-BLO	FU-4
	.25A (EUROPE)	FU-17
J1002	CONN,MALE,5 PIN	CS-288-5
J1017	TERMINAL,TEFLON	TE-113
J1018	CONN,BERG,1 PIN	CS-339-1
J1021		CS-724-6
J1024	LATCHING HEADER,FRICTON, SGL ROW	CS-724-3
K104,107,109, 110	RELAY (SPST)	RL-117
K105,106,108	RELAY (SPST),GORDOS,4705S	RL-131

L101	CHOKE, 100UH	CH-14
P1005	CABLE ASSEMBLY, 20 CONDUCTOR	CA-27-9B
P1006	CONNECTOR, HOUSING	CS-716-4
Q108	TRANS, LOW NOISE/DRIFT DUAL FET,MP841	TG-200
Q109,117	TRANS,NPN SILICON,2N3904 (T0-92)	TG-47
Q110	TRANS,N-CHANNEL FET,TN06L	TG-216
Q111	TRANS,N CHANNEL FET,2N4392 (TO-92)	TG-128-1
Q112	TRANS, N CHANNEL JFET,PN5434(TO-92)	TG-174-1
Q116	TRANS,N CHANNEL JFET,SELECTED J210	TG-167-1
Q119	TRANS, DUAL NPN IT121 (TO-52)	TG-91
R118	RES,470,5%,1/4W,COMPOSITION OR FILM	R-76-470
R119	RES,330,5%,1/4W,COMPOSITION OR FILM	R-76-330
R120,124,131, 162	RES,1K,5%,1/4W,COMPOSITION OR FILM	R-76-1K
R121..123	RES,270,5%,1/4W,COMPOSITION OR FILM	R-76-270
R134	RES,100K,.1%,1/10W,METAL FILM	R-263-100K
R135	RES,142.2K,.02%,1/8W,PRECISION THIN FILM	R-365-142.2K
R136,137	RES,20K,1%,1/8W,METAL FILM	R-88-20K
R138	RES,200,5%,1/4W,COMPOSITION OR FILM	R-76-200
R139	RES,15.4K,1%,1/8W,METAL FILM	R-88-15.4K
R140	RES,4.5K,.1%,1/10W,METAL FILM	R-263-4.5K
R141,160,163, 176,228..230	RES,10K,5%,1/4W,COMPOSITION OR FILM	R-76-10K
R142	RES,243,1%,1/8W,METAL FILM	R-88-243
R143	RES,10K,1%,1/8W,METAL FILM	R-88-10K
R144	RES,7.39K,.1%,1/10W,METAL FILM	R-263-7.39K
R145	RES,1K,.1%,1W,WIREWOUND	R-249-1K
R147	RES,1.24K,1%,1/8W,METAL FILM	R-88-1.24K
R148	RES,11K,.1%,1/10W,METAL FILM	R-263-11K
R149	RES,1.1M,.1%,1/8W,METAL FILM	R-176-1.1M
R150	RES,996K,.1%,1/4W,METAL FILM	R-264-996K
R153	RES,10M,.25%,1/8W,FIXED METAL FILM	R-305-10M
R156,158	RES,7.87K,1%,1/8W,METAL FILM	R-88-7.87K
R157	RES,7.78K,.02%,1/8W,PRECISION THIN FILM	R-365-7.78K
R159	RES,110M,.50%,1/4W,METAL OXIDE	R-269-110M
R161	RES,2.15K,1%,1/8W,METAL FILM	R-88-2.15K
R164	RES,2K,1%,1/8,METAL FILM	R-88-2K
R165	RES,39.2K,1%,1/8W METAL FILM	R-88-39.2K
R169,211	RES,100,1%,1/8W,METAL FILM	R-88-100
R171	RES,1G,2%,1.5W,HY MEG	R-289-1G
R175	RES,5.1K,5%,1/4W,COMPOSITION OR FILM	R-76-5.1K
R177	RES,15K,5%,1/4W,COMPOSITION OR FILM	R-76-15K
R179	RES,6.2K,5%,1/4W COMPOSITION OR FILM	R-76-6.2K
R180	RES,560K,5%,1/4W,COMPOSITION OR FILM	R-76-560K
R181,217	RES,47K,5%,1/4W,COMPOSITION OR FILM	R-76-47K
R182	RES,2K,5%,1/4,COMPOSITION OR FILM	R-76-2K
R185	RES,4.87K,1%,1/8W,METAL FILM	R-88-4.87K
R186	RES,26.7K,1%,1/8W,METAL FILM	R-88-26.7K
R187	RES,15.8K,1%,1/8W,METAL FILM	R-88-15.8K
R189,197	RES,1.5K,.5%,3/4W, FIXED METAL FILM	R-303-1.5K
R191	RES,10,5%,1/4W,COMPOSITION OR FILM	R-76-10
R192,188	RESISTOR SET	R-363
R193	RES, 10M,.1%,1/2W, 350V COMPOSITION	R-333-10M
R194	RES,220K,5%,1/4W,COMPOSITION OR FILM	R-76-220K

R195	RES, 150K,1% 1/8W, METAL FILM	R-88-150K
R198	POT,50K,10%,.5W,NON-WIREWOUND	RP-97-50K
R200	RES,22,5%,1/4W,COMPOSITION OR FILM	R-76-22
R203	RES, 1K,1%,1/2W FUSIBLE METAL FILM	R-370-1K
R204	RES,120K,5%,1/4W,COMPOSITION OR FILM	R-76-120K
R206	RES,909,1%,1/8W,METAL FILM	R-88-909
R207	RES NET,10K,.5%,.150W	TF-220-10K
R208	RES, 3K,5%,1/4W, COMPOSITION OR FILM	R-76-3K
R209	RES,220,5%,1/4W, COMPOSITION OR FILM	R-76-220
R210	RES,47,5%,1/4W,COMPOSITION OR FILM	R-76-47
R213	RES,182,1%,1/8W,METAL FILM	R-88-182
R214	RES, 301, 1% 1/8W, METAL FILM	R-88-301
R215,220	RES,10,5%,1/4W,COMPOSITION OR FILM	R-76-10
R216	RES,10M,5%,1/4W,COMPOSITION OR FILM	R-76-10M
R219	RES,560,5%,1/4W,COMPOSITION OR FILM	R-76-560
R226		R-169-100K
R227	RES, 15, 5%, 1/4 COMPOSITION OR FILM	R-76-15
R231	RES,10K,5%,1/4W,COMPOSITION OR FILM	R-76-10K
S100	SWITCH,SLIDE (DPDT)	SW-476
S101	SWITCH,PUSHBUTTON (6 POLE)	SW-466
S102	SWITCH,PUSHBUTTON (2 POLE)	SW-469
T100	TRANSFORMER	TR-271B
	(JAPAN)	TR-274B
TE100..107,	TERMINAL (TEFLON)	TE-97-1
109,111,112		
TP101,102,	CONN,TEST POINT	CS-553
104,105,107		
U103,105,109	IC,OPTOCOUPLER,TLP582	IC-689
U104	IC,OPTOCOUPLER,2611	IC-690
U106	IC,POS VOLTAGE REG +15V,500MA,7815	IC-194
U107	IC,+5V VOLTAGE REGULATOR, 7805	IC-93
U108	IC,NEG VOLTAGE REG -15V,500MA,79M15	IC-195
U111	IC,BUF/LINE DRIVER & RECEIVER,74HC240	IC-617
U112,124	IC,TRIPLE 2 CH MULTI/DEMUX,4053	IC-283-1
U113	IC,DUAL LOW NOISE OP-AMP,5534	IC-540
U114	IC,22V OP-AMP,OP-07	IC-207
U115	IC,DUAL LOW NOISE OP-AMP,NE5532	IC-501
U116,137	IC,HEX INVERTER,74HC04	IC-354
U120	IC,8 BIT IDENTITY COMP,74HC688	IC-488
U121	IC,QUAD COMPARATOR,LM339	IC-219
U122,126,134,	IC,8-STAGE SHIFT/STORE REG,74HCT4094	IC-691
136		
U123	IC,OCTAL BUFFER,74HC244N	IC-469
U128,138	IC,DUAL 4 BIT COUNTER,74HCT393	IC-462
U129	IC,QUAD 2 INPUT NOR,74HC02	IC-412
U132,146	IC,JFET OP-AMP,LF411	IC-453
U135	IC,DUAL 4 BIT DECADE COUNTER,74HC390	IC-500
U139	IC,QUAD 2 INPUT NAND,74HC00	IC-351
U140,141	IC,DUAL D-TYPE FLIP FLOP,74HC74	IC-337
U142	IC,OP-AMP,OPA128	IC-542
U144,145	IC,SPST CMOS ANALOG SWITCH, (DG411)	IC-667
U147	IC,20V OP-AMP,1012	IC-394

VR103	DIODE,ZENER 6.4V,IN4579 (DO-7)	DZ-73
VR104,105	DIODE,ZENER 6.44V,IN4577AGED (DO-7)	DZ-58
Y100	CRYSTAL,3.84MHZ	CR-13

MODEL 487 ANALOG BOARD, PARTS LIST

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
	PUSHBUTTON	31470-2B
	FUSE HOLDER	FH-21
	CONNECTOR	CS-276
	STANDOFF	ST-195-2
	STANDOFF	ST-139-18
	HEAT SINK	HS-41
	FUSE CARRIER	FH-25
	CONN,BERG	CS-339
AT100,101	IC,PHOTO COUPLER,PS2501A-1	IC-670
C100,101,108, 114	CAP,2200,20%,35V,ALUM ELECTROLY	C-428-2200
C102,110..112, 121..123,220, 222,224	CAP, 10UF,-20+100%,25V,ALUM ELEC	C-314-10
C103,109	CAP,33UF,-10%+50%,400V,ALUM ELECTROLYTIC	C-419-33
C104,105	CAP,.05,+80-20%,1000V,CERAMIC	C-298-.05
C106,107,174	CAP,.01UF,20%,500V,CERAMIC	C-22-.01
C113,154	CAP,390PF,10%,1000V,CERAMIC	C-64-390P
C115	CAP,10,000UF,-20+100%,16V ALUMINUM	C-313-10000
C116,169	CAP,150PF,10%,1000V,CERAMIC	C-64-150P
C117	CAP,1500UF,-20,+100%,25V,ALUM ELEC	C-314-1500
C118,120,124, 146,157,170, 175,195.198, 221,223,225	CAP,.1UF,20%,50V,CERAMIC	C-237-.1
C119,126..130, 134,138..140, 199..217	CAP,.1UF,20%,50V,CERAMIC	C-365-.1
C125	CAP,1500PF,10%,1000V,CERMANIC	C-64-1500P
C126,226	CAP,.01UF,10%,1000V,CERAMIC	C-64-.01
C131,171	CAP,330PF,10%,1000V,CERAMIC	C-64-330P
C132	CAP,22PF,20%,500V,CERAMIC	C-22-22P
C133	CAP,820PF,10%,1000V,CERAMIC	C-64-820P
C135,172,177	CAP,100PF,10%,1000V,CERAMIC	C-64-100P
C137	CAP,.0033,20%,500V, CERAMIC	C-22-.0033
C141	CAP,.0047UF,10%,100V,POLYPROPYLENE	C-306-.0047
C145,147	CAP,22PF,10%,1000V,CERAMIC	C-64-22P
C148,159	CAP,10PF,10%,1000V,CERAMIC	C-64-10P
C150	CAP,22UF,10%,16V,ALUM ELEC	C-361-22
C155	CAP,710PF,2%,50V,CERAMIC	C-348-710P
C156,160,167	CAP,.01UF,20%,50V,CERAMIC	C-237-.01
C158	CAP,3.3PF,.5%,1000V,CERAMIC	C-308-3.3P
C173	CAP,47PF,10%,1000V,CERAMIC	C-64-47P
C178	CAP,1UF,20%,50V,POLYCARBONATE	C-215-1
C189	CAP,10UF,10%,20V,TANTALUM ELECTROLYTE	C-204-10
C190	CAP,.68,.20%,50V POLYESTER	C-344-.68
C191	CAP,.33,.20%,50V POLYESTER	C-344-.33
C192	CAP, .02,20%,.500V CERAMIC	C-22-.02
C218,136,143	CAP,1UF,20%,50V, CERAMIC	C-237-1

C226	CAP,1000PF,10%,1000V,CERAMIC	C-64-1000P
CR100	DIODE,SILICON,IN4006 (D0-41)	RF-38
CR101,102, 104,105,107	DIODE,SILICON,IN4006 (D0-41)	RF-38
CR103,117	DIODE,BRIDGE,VM18	RF-52
CR106,108	DIODE,SILICON,W04M (CASE WM)	RF-46
CR109	DIODE, BRIDGE PE05	RF-48
CR110..116	DIODE,SILICON,IN4148 (DO-35)	RF-28
F100	FUSE .5A,250V,3AG, SLO-BLO	FU-4
	.25A (EUROPE)	FU-17
J1002	CONN,MALE,5 PIN	CS-288-5
J1017	TERMINAL,TEFLON	TE-113
J1018	CONN,BERG,1 PIN	CS-339-1
J1021	CS-724-6	
J1024,1026	LATCHING HEADER,FRICTON, SGL ROW	CS-724-3
K100	RELAY,REED HI VOLTAGE	RL-119
K101,102	1 AMP SENSITIVE DIP RELAY	RL-142
K103	RELAY,REED HI VOLTAGE	RL-129
K104,107, 109,110	RELAY (SPST)	RL-117
K105,106,108	RELAY (SPST),GORDOS,4705S	RL-131
L101	CHOKE, 100UH	CH-14
P1005	CABLE ASSEMBLY, 20 CONDUCTOR	CA-27-9B
P1006	CONNECTOR, HOUSING	CS-716-4
Q100,102,103, 107,109, 113..115,117	TRANS,NPN SILICON,2N3904 (T0-92)	TG-47
Q101,104..106	TRANS, NCHANNEL PWR FET,MTPIN100(T0-220)	TG-222
Q108	TRANS, LOW NOISE/DRIFT DUAL FET,MP841	TG-200
Q110	TRANS,N-CHANNEL FET,TN06L	TG-216
Q111,Q120	TRANS,N CHANNEL FET,2N4392 (TO-92)	TG-128-1
Q112	TRANS, N CHANNEL JFET,PN5434(TO-92)	TG-174-1
Q116	TRANS,N CHANNEL JFET,SELECTED J210	TG-167-1
Q119	TRANS, DUAL NPN IT121 (TO-52)	TG-91
R100,114,117	RES,2M,.1%,1/2W,METAL FILM	R-174-2M
R101	RES,3.9K,5%,1/4W,COMPOSITION OR FILM	R-76-3.9K
R102	RES,2.2K,5%,1/4W,COMPOSITION OR FILM	R-76-2.2K
R103	RES,2.2M,5%,1/4W,COMPOSITION OR FILM	R-76-2.2M
R104,151	RES,100,5%,1/4W,COMPOSITION OR FILM	R-76-100
R105	RES, 1K, 10% .1W COMPOSITION	R-2-1K
R106,116,141, 152,160,163, 176,228.230, 232.234,235	RES,10K,5%,1/4W,COMPOSITION OR FILM	R-76-10K
R107,113	RES,1M,0.1%,1/4W,METAL FILM	R-374-1M
R108	RES,180,5%,1/4W,COMPOSITION OR FILM	R-76-180
R109,R125	RES,20K,5%,1/4W,COMPOSITION OR FILM	R-76-20K
R110	RES,220K,.1%,1/4W,METAL FILM	R-264-220K

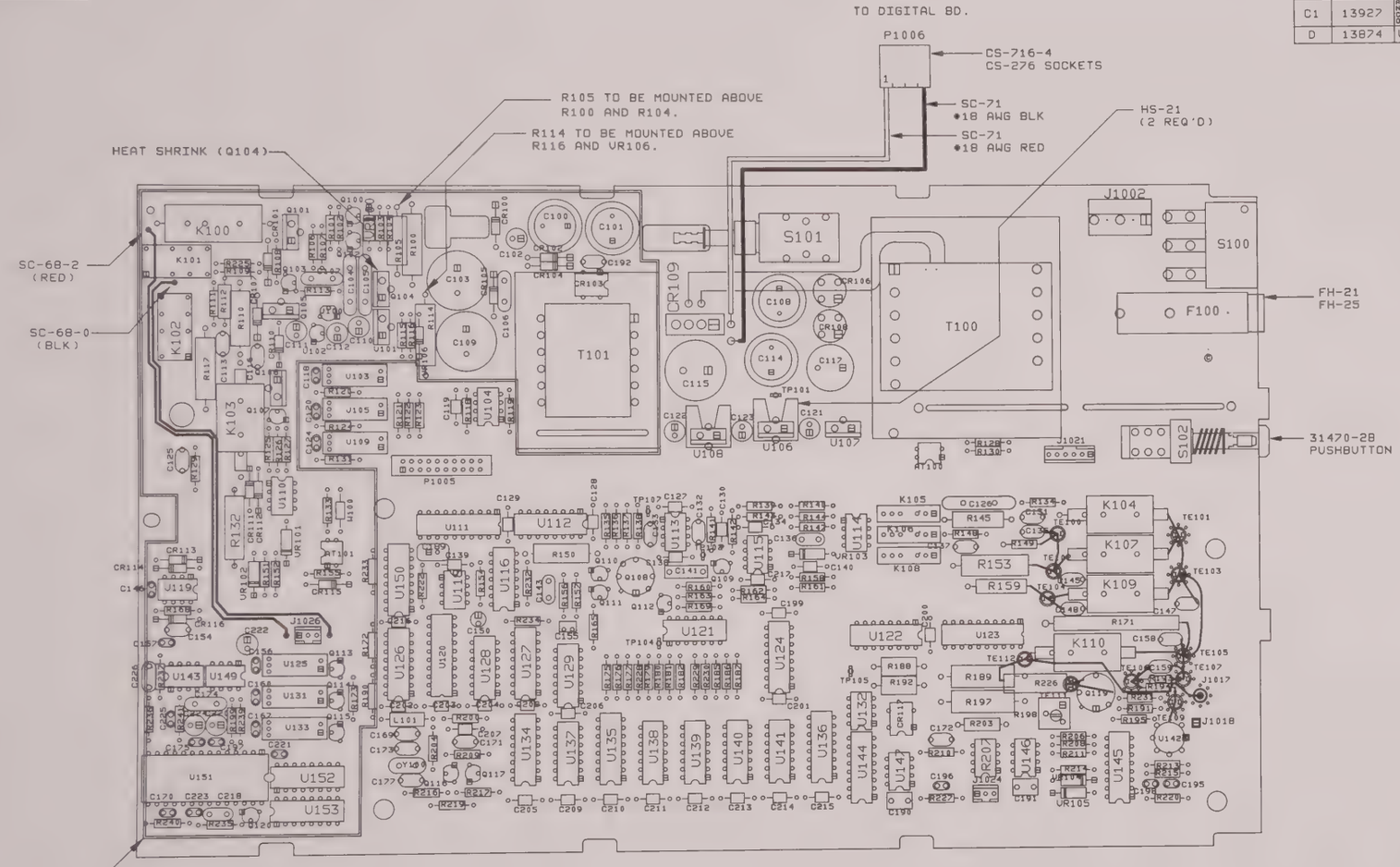
R111,120,124, 128,129,131, 133,154,162	RES,1K,5%,1/4W,COMPOSITION OR FILM	R-76-1K
R112	RES, 2191,1%,.1W METAL FILM	R-241-2191
R115	RES,4.7K,5%,1/4W,COMPOSITION OR FILM	R-76-4.7K
R118	RES,470,5%,1/4W,COMPOSITION OR FILM	R-76-470
R119	RES,330,5%,1/4W,COMPOSITION OR FILM	R-76-330
R121..123, 172,173,190	RES,270,5%,1/4W,COMPOSITION OR FILM	R-76-270
R126	RES,619,1%,1/8W,METAL FILM	R-88-619
R127	RES,5.6K,5%,1/4W,COMPOSITION OR FILM	R-76-5.6K
R130,219	RES,560,5%,1/4W,COMPOSITION OR FILM	R-76-560
R132	RES,30.51K,.1%,1/2W, METAL FILM	R-169-30.51K
R134	RES,100K,.1%,1/10W,METAL FILM	R-263-100K
R135	RES,142.2K,.02%,1/8W,PRECISION THIN FILM	R-365-142.2K
R136,137	RES,20K,1%,1/8W,METAL FILM	R-88-20K
R138	RES,200,5%,1/4W,COMPOSITION OR FILM	R-76-200
R139	RES,15.4K,1%,1/8W,METAL FILM	R-88-15.4K
R140	RES,4.5K,.1%,1/10W,METAL FILM	R-263-4.5K
R142	RES,243,1%,1/8W,METAL FILM	R-88-243
R143,239	RES,10K,1%,1/8W,METAL FILM	R-88-10K
R144	RES,7.39K,.1%,1/10W,METAL FILM	R-263-7.39K
R145	RES,1K,.1%,1W,WIREWOUND	R-249-1K
R147	RES,1.24K,1%,1/8W,METAL FILM	R-88-1.24K
R148	RES,11K,.1%,1/10W,METAL FILM	R-263-11K
R149	RES,1.1M,.1%,1/8W,METAL FILM	R-176-1.1M
R150	RES,996K,.1%,1/4W,METAL FILM	R-264-996K
R153	RES,10M,.25%,1/8W,FIXED METAL FILM	R-305-10M
R155	RES,820,5%,1/4W,COMPOSITION OR FILM	R-76-820
R156,158	RES,7.87K,1%,1/8W,METAL FILM	R-88-7.87K
R157	RES,7.78K,.02%,1/8W,PRECISION THIN FILM	R-365-7.78K
R159	RES,110M,.50%,1/4W,METAL OXIDE	R-269-110M
R161	RES,2.15K,1%,1/8W,METAL FILM	R-88-2.15K
R164	RES,2K,1%,1/8,METAL FILM	R-88-2K
R165	RES,39.2K,1%,1/8W METAL FILM	R-88-39.2K
R168	RES,432,1%,1/8W,METAL FILM	R-88-432K
R169	RES,100,1%,1/8W,METAL FILM	R-88-100
R171	RES,1G,2%,1.5W,HY MEG	R-289-1G
R175	RES,5.1K,5%,1/4W,COMPOSITION OR FILM	R-76-5.1K
R177	RES,15K,5%,1/4W,COMPOSITION OR FILM	R-76-15K
R179	RES,6.2K,5%,1/4W COMPOSITION OR FILM	R-76-6.2K
R180	RES,560K,5%,1/4W,COMPOSITION OR FILM	R-76-560K
R181,217	RES,47K,5%,1/4W,COMPOSITION OR FILM	R-76-47K
R182	RES,2K,5%,1/4,COMPOSITION OR FILM	R-76-2K
R185	RES,4.87K,1%,1/8W,METAL FILM	R-88-4.87K
R186	RES,26.7K,1%,1/8W,METAL FILM	R-88-26.7K
R187	RES,15.8K,1%,1/8W,METAL FILM	R-88-15.8K
R188,192	15K=R192, 18.6K=R188 RESISTOR SET	R-363
R189,197	RES,1.5K,.5%,3/4W, FIXED METAL FILM	R-303-1.5K
R191	RES,10,5%,1/4W,COMPOSITION OR FILM	R-76-10
R193	RES, 10M,.1%,1/2W, 350V COMPOSITION	R-333-10M
R194	RES,220K,5%,1/4W,COMPOSITION OR FILM	R-76-220K
R195	RES, 150K,1% 1/8W, METAL FILM	R-88-150K
R198	POT,50K,10%,.5W,NON-WIREWOUND	RP-97-50K
R199	RES,10,1%,1/8W,METAL FILM	R-88-10
R199,215,220	RES,10,5%,1/4W,COMPOSITION OR FILM	R-76-10
R200	RES,22,5%,1/4W,COMPOSITION OR FILM	R-76-22
R203	RES, 1K,1%,1/2W FUSIBLE METAL FILM	R-370-1K

R204	RES,120K,5%,1/4W,COMPOSITION OR FILM	R-76-120K
R206	RES,909,1%,1/8W,METAL FILM	R-88-909
R207	RES NET,10K,.5%,.150W	TF-220-10K
R208	RES, 3K,5%,1/4W, COMPOSITION OR FILM	R-76-3K
R209	RES,220,5%,1/4W, COMPOSITION OR FILM	R-76-220
R210	RES,47,5%,1/4W,COMPOSITION OR FILM	R-76-47
R211	RES,100,1%,1/8W,METAL FILM	R-88-100
R213	RES,182,1%,1/8W,METAL FILM	R-88-182
R214	RES, 301, 1% 1/8W, METAL FILM	R-88-301
R216	RES,10M,5%,1/4W,COMPOSITION OR FILM	R-76-10M
R222	RES, 7.5K, 1%, 1/8W METAL FILM	R-88-7.5K
R225	RES,1K,1%,1/8W,METAL FILM	R-88-1K
R226		R-169-100K
R227	RES, 15, 5%, 1/4 COMPOSITION OR FILM	R-76-15
R231	RES,10K,5%,1/4W,COMPOSITION OR FILM	R-76-10K
R236,237	RES,20K,.1%,1/10W,METAL FILM	R-263-20K
R240	RES,100K,5%,1/4W,COMPOSITION OR FILM	R-76-100K
R241		R-88-20
S100	SWITCH,SLIDE (DPDT)	SW-476
S101	SWITCH,PUSHBUTTON (6 POLE)	SW-466
S102	SWITCH,PUSHBUTTON (2 POLE)	SW-469
T100	TRANSFORMER	TR-271B
	TR-274B (JAPAN)	TR-274B
T101	TRANSFORMER	TR-272B
	(JAPAN)	TR-273B
TE100,101.. 107,109,111, 112	TERMINAL (TEFLON)	TE-97-1
TP101,102,104, 105,107	CONN,TEST POINT	CS-553
U100	IC,POS VOLTAGE REG +15V,78L15	IC-170
U101	IC,NEG VOLTAGE REG +15V,500MA,7915	IC-174
U102	IC,VAR POS VOLTAGE REG,100MA,78L05A	IC-223
U103,105,109, 125,131,133	IC,OPTOCOUPLER,TLP582	IC-689
U104	IC,OPTOCOUPLER,2611	IC-690
U106	IC,POS VOLTAGE REG +15V,500MA,7815	IC-194
U107	IC,+5V VOLTAGE REGULATOR, 7805	IC-93
U108	IC,NEG VOLTAGE REG -15V,500MA,79M15	IC-195
U110,119,143, 147	IC,20V OP-AMP,1012	IC-394
U111	IC,BUF/LINE DRIVER & RECEIVER,74HC240	IC-617
U112,124	IC,TRIPLE 2 CH MULTI/DEMUX,4053	IC-283-1
U113	IC,DUAL LOW NOISE OP-AMP,5534	IC-540
U114	IC,22V OP-AMP,OP-07	IC-207
U115	IC,DUAL LOW NOISE OP-AMP,NE5532	IC-501
U116,U137	IC,HEX INVERTER,74HC04	IC-354
U118	IC,SUPPLY VOLTAGE SUPERVISOR,TL7705AC	IC-602
U120	IC,8 BIT IDENTITY COMP,74HC688	IC-488
U121	IC,QUAD COMPARATOR,LM339	IC-219
U122,126,134, 136,152,153	IC,8-STAGE SHIFT/STORE REG,74HCT4094	IC-691
U123	IC,OCTAL BUFFER,74HC244N	IC-469
U127	IC,DARLINGTON ARRAY,2003	IC-206

U128,138	IC,DUAL 4 BIT COUNTER,74HCT393	IC-462
U129	IC,QUAD 2 INPUT NOR,74HC02	IC-412
U132,146	IC,JFET OP-AMP,LF411	IC-453
U135	IC,DUAL 4 BIT DECADE COUNTER,74HC390	IC-500
U139	IC,QUAD 2 INPUT NAND,74HC00	IC-351
U140,141	IC,DUAL D-TYPE FLIP FLOP,74HC74	IC-337
U142	IC,OP-AMP,OPA128	IC-542
U144,145	IC,SPST CMOS ANALOG SWITCH, (DG411)	IC-667
U149	IC,5V REFERENCE,AD586L	IC-681
U150	IC, DUAL RETRIGG, MULTIVIBRATOR4538	IC-718
U151	IC 16 BIT VOLTAGE OUTPUT DAC	IC-734
VR100	DIODE,ZENER 24V,IN723 (D0-7)	DZ-17
VR101,102, 104,105	DIODE,ZENER 6.44V,IN4577AGED (DO-7)	DZ-58
VR103	DIODE,ZENER 6.4V,IN4579 (DO-7)	DZ-73
VR106	DIODE, ZENER 30V IN4751 (DO-35)	DZ-78
W100	JUMPER	J-15
Y100	CRYSTAL,3.84MHZ	CR-13

NO. 487-100

LTR.	ECO NO.	REVISION	ENG.	DATE
C	891222	RELEASED	B	12-28-89
C1	13927	ADDED T151 TO PARTS NOT INSTALLED FOR 486 AND NOTE FOR PARTS NOT TO BE INSTALLED FOR 487. CHG'D ORIENTATION OF TE108-TE107 AND CONN. OF K110 FROM TE106 TO TE105.		3-5-90
D	13874	UPDATED	MS	3-29-90

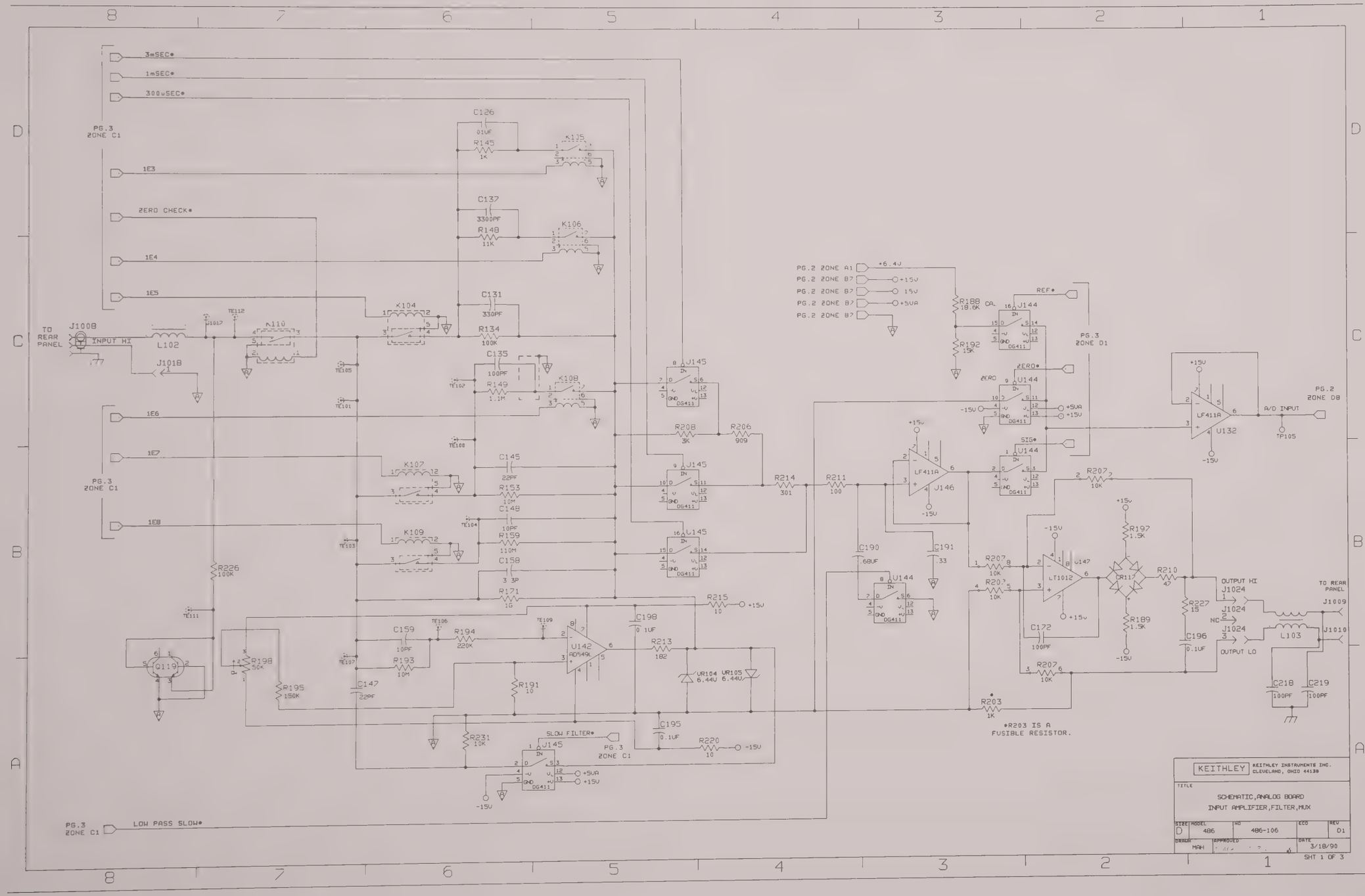


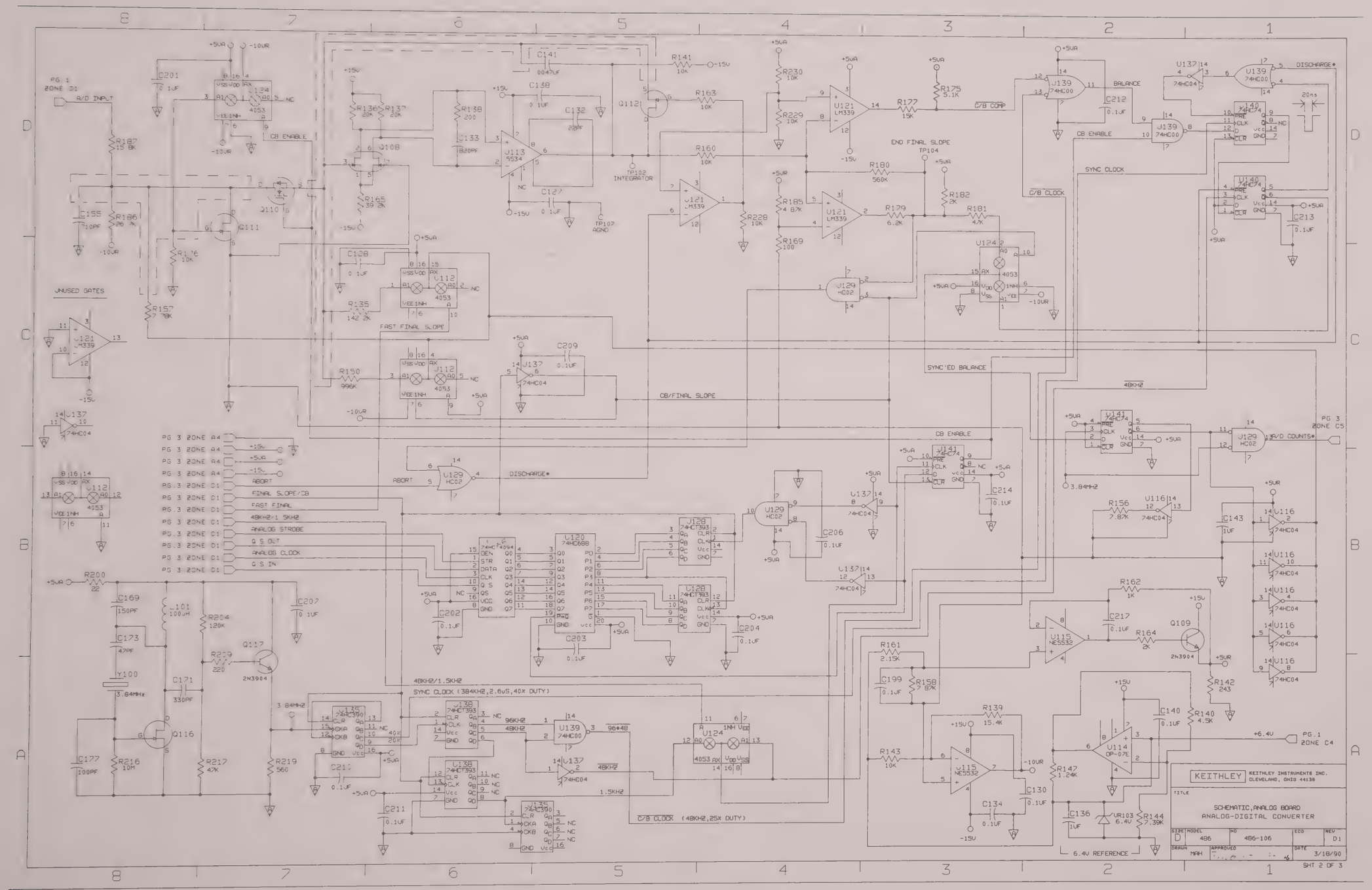
NOTE:
FOR MORE COMPONENT INFORMATION
REFER TO 486 AND 487 PRODUCT
STRUCTURE.

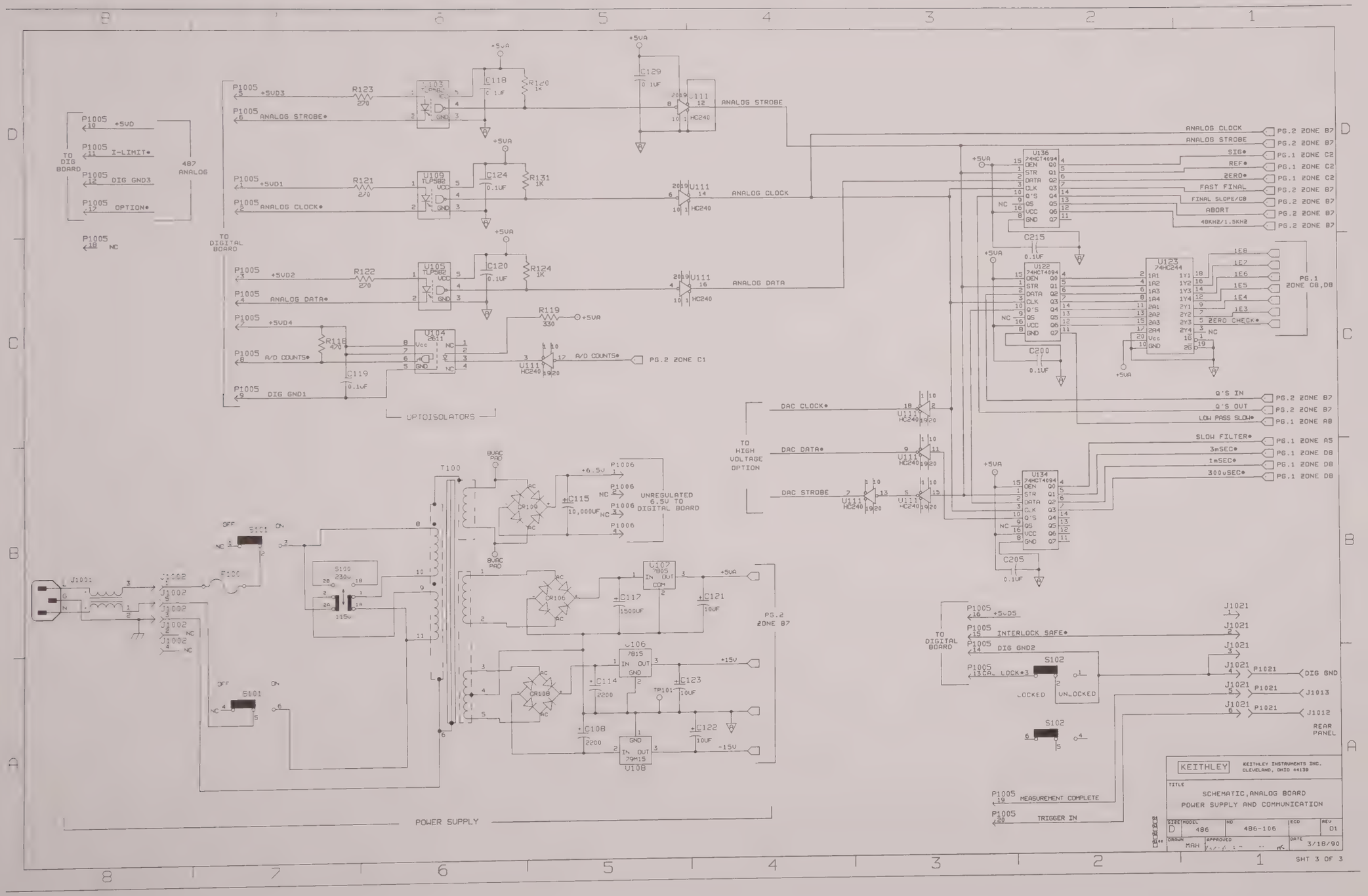
MODEL	NEXT ASSEMBLY	QTY.
487		
486		

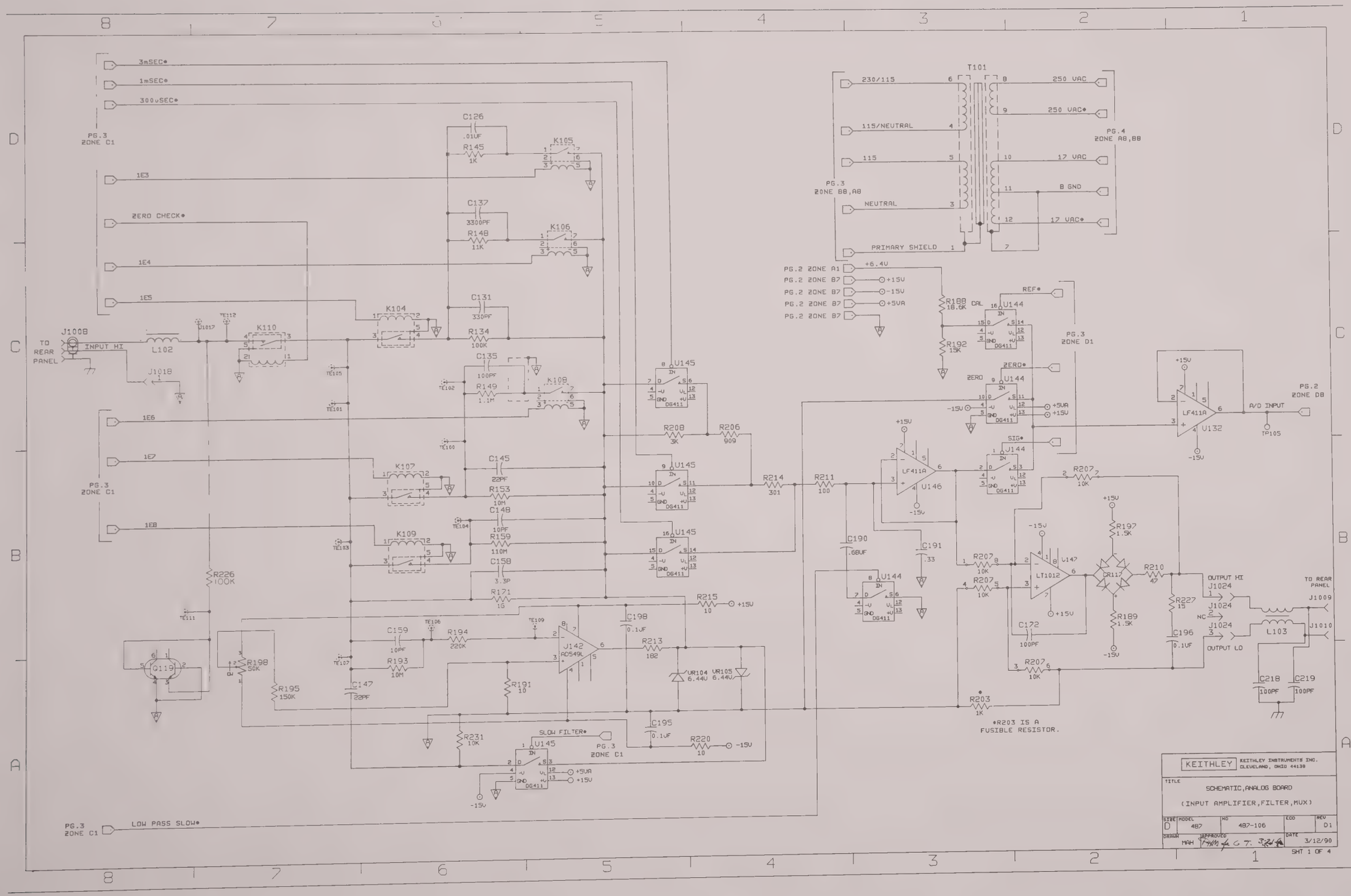
USED ON

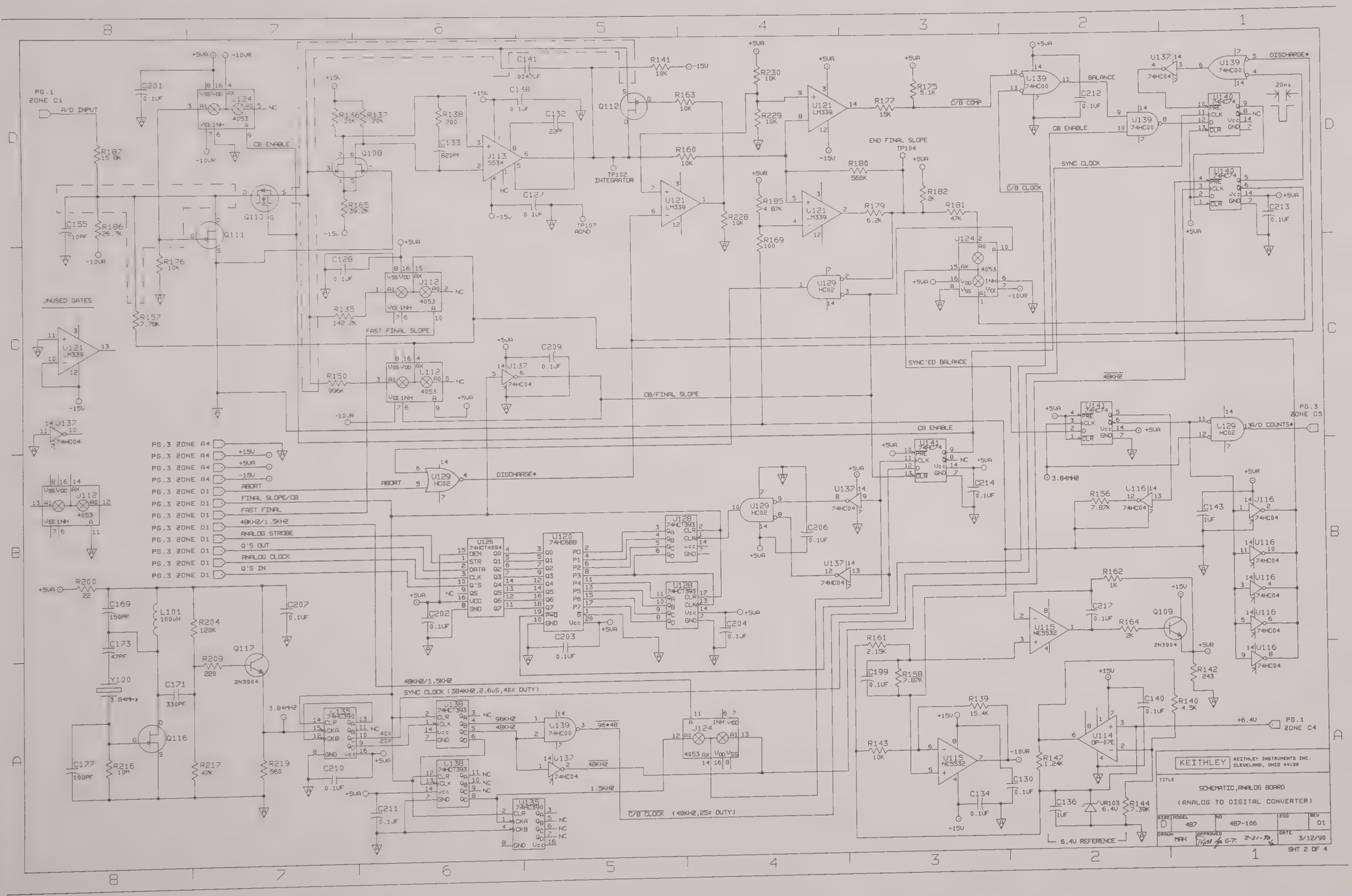
DO NOT SCALE THIS DRAWING	DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED	DATE 12/22/89	SCALE 1:1	TITLE	COMPONENT LAYOUT, ANALOG BOARD
KEITHLEY KEITHLEY INSTRUMENTS INC. CLEVELAND, OHIO 44139	XX=±.015 ANG.=±1°	DRN. MAH	ENG APPR.		
	XXX=±.005 FRAC.=±1/64	MATERIAL		C	NO. 487-100
	SURFACE MAX. 63	FINISH			

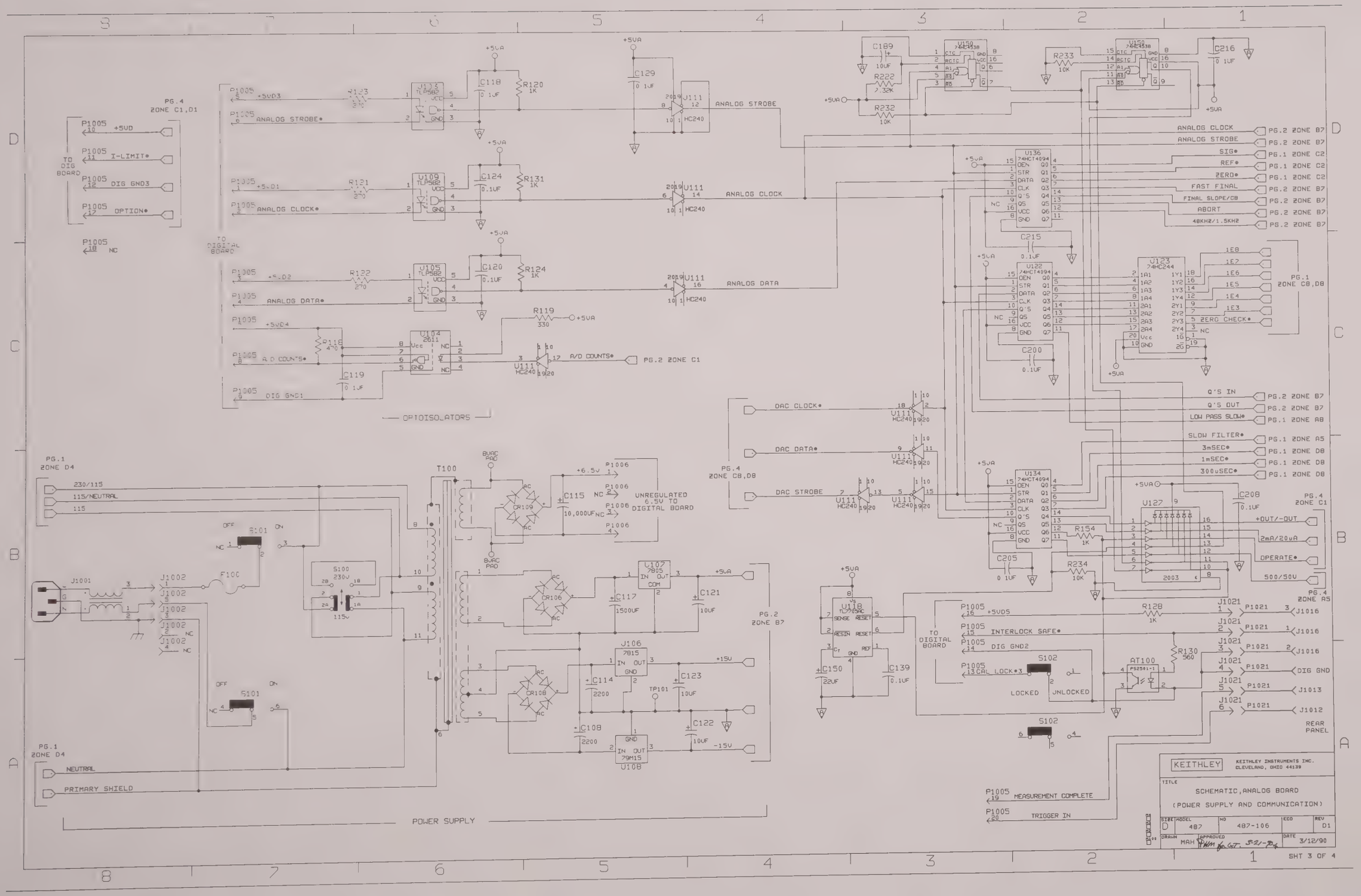

3mSEC*
1mSEC*
300uSEC*
PG.3 ZONE C1
1E3
ZERO CHECK*
1E4
1E5
1E6
1E7
1E8
PG.3 ZONE C1
TO REAR PANEL
J1008
INPUT HI
L102
J1018
K110
K104
K107
K109
K105
K106
K108
C126
.01UF
R145
1K
C137
3300PF
R148
11K
C131
330PF
R134
100K
C135
100PF
R149
1.1M
C145
22PF
R153
10M
C148
10PF
R159
110M
C158
3.3P
R171
1G
R226
100K
C159
10PF
R193
10M
R194
220K
C147
22PF
R195
150K
R198
50K
Q119
R191
10
C198
.1UF
R213
182
R215
10
+15V
VR104 6.44V
VR105 6.44V
R231
10K
SLOW FILTER*
PG.3 ZONE C1
C195
.1UF
R220
10
-15V
LOW PASS SLOW*
PG.3 ZONE C1
U142
AD549L
U145
DG411
R208
3K
R206
909
R214
301
R211
100
PG.2 ZONE A1
PG.2 ZONE B7
PG.2 ZONE B7
PG.2 ZONE B7
PG.2 ZONE B7
+6.4V
+15V
15V
+5VA
R188
18.6K
R192
15K
REF*
ZERO*
SIG*
U144
PG.3 ZONE D1
+5VA
+15V
-15V
U146
LF411A
C190
.68UF
C191
.33
R207
10K
U147
LT1012
CR117
R197
1.5K
R189
1.5K
R210
47
R227
15
C196
.1UF
C172
100PF
R203
1K
*R203 IS A FUSIBLE RESISTOR.
U132
LF411A
A/D INPUT
TP105
PG.2 ZONE D8
OUTPUT HI
OUTPUT LO
NC
J1024
TO REAR PANEL
J1009
J1010
L103
C218
100PF
C219
100PF
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
TITLE
SCHEMATIC,ANALOG BOARD
INPUT AMPLIFIER,FILTER,MUX
SIZE D
MODEL 486
NO 486-106
ECO
REV D1
DRAWN MAH
APPROVED
DATE 3/18/90
SHT 1 OF 3

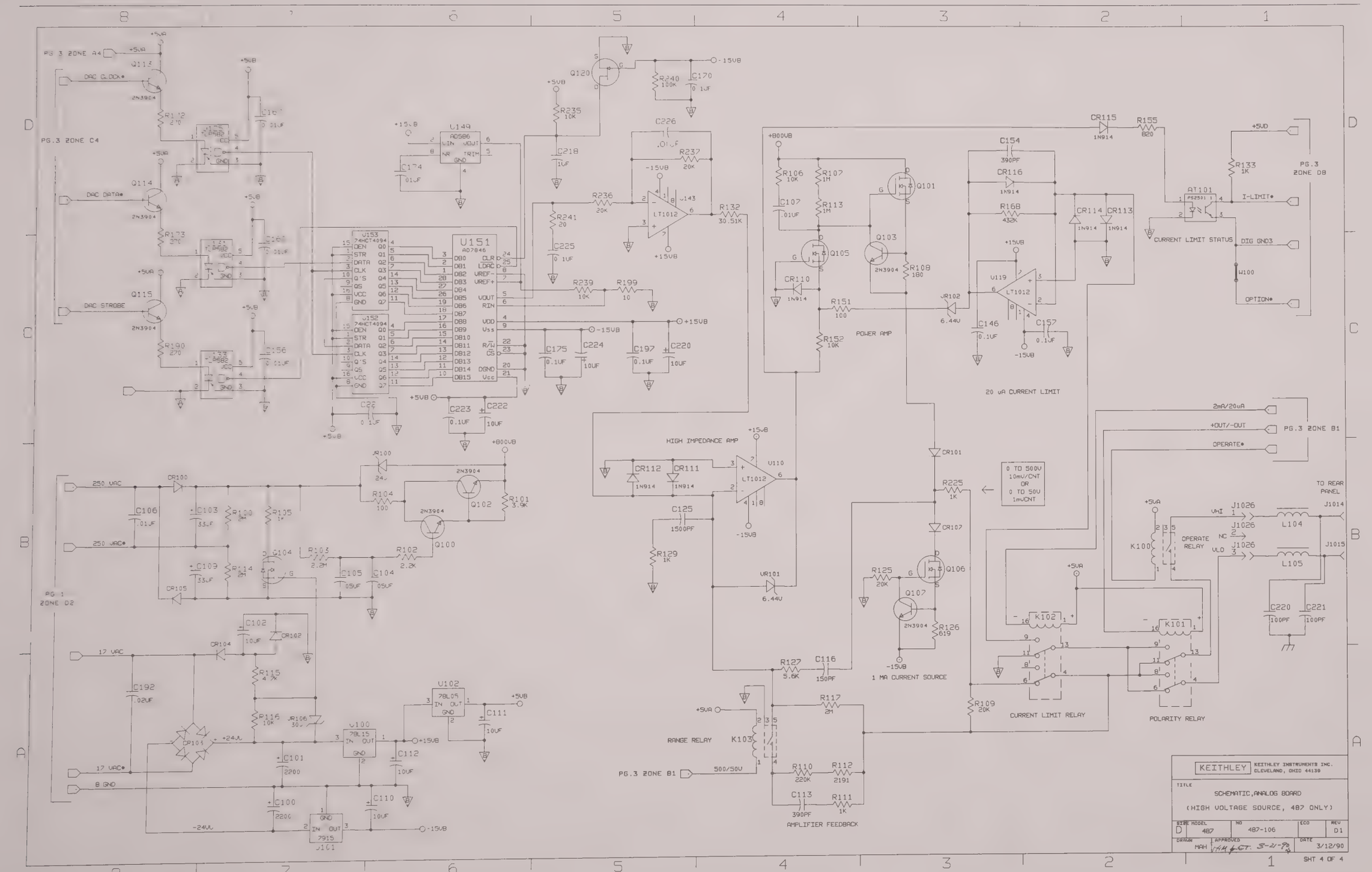

KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
SCHEMATIC, ANALOG BOARD
ANALOG-DIGITAL CONVERTER
MODEL 486
NO 486-106
ECO
REV D1
DRAWN MAH
APPROVED
DATE 3/18/90
SHT 2 OF 3
A/D INPUT
CB ENABLE
UNUSED GATES
FAST FINAL SLOPE
CB/FINAL SLOPE
SYNC'ED BALANCE
END FINAL SLOPE
SYNC CLOCK
C/B CLOCK
C/B COMP
BALANCE
DISCHARGE*
ABORT
FINAL SLOPE/CB
FAST FINAL
48KHZ/1.5KHZ
ANALOG STROBE
Q S OUT
Q S IN
SYNC CLOCK (384KHZ,2.6uS,40% DUTY)
C/B CLOCK (48KHZ,25% DUTY)
6.4V REFERENCE
A/D COUNTS*
INTEGRATOR
AGND


TO DIG BOARD
P100S +5VD
P100S I-LIMIT*
P100S DIG GND3
P100S OPTION*
487 ANALOG
P1005 NC
TO DIGITAL BOARD
P1005 +5VD3
P1005 ANALOG STROBE*
R123 270
U103 TLP560
C118 0.1UF
R130 1K
+5VA
C129 0.1UF
U111 HC240
ANALOG STROBE
P1005 +5VD1
P1005 ANALOG CLOCK*
R121 270
U109 TLP560
C124 0.1UF
R131 1K
ANALOG CLOCK
P1005 +5VD2
P1005 ANALOG DATA*
R122 270
U105 TLP560
C120 0.1UF
R124 1K
ANALOG DATA
P1005 +5VD4
P1005 A/D COUNTS*
R118 470
U104 2611
C119 0.1uF
R119 330
A/D COUNTS*
PG.2 ZONE C1
P1005 DIG GND1
OPTOISOLATORS
ANALOG CLOCK
ANALOG STROBE
SIG*
REF*
ZERO*
FAST FINAL
FINAL SLOPE/CB
ABORT
48KHZ/1.5KHZ
PG.2 ZONE B7
PG.1 ZONE C2
U136 74HCT4094
U122 74HCT4094
U123 74HC244
C215 0.1UF
C200 0.1UF
1E8
1E7
1E6
1E5
1E4
1E3
2ERO CHECK*
NC
PG.1 ZONE C8,D8
Q'S IN
Q'S OUT
LOW PASS SLOW*
PG.2 ZONE B7
PG.1 ZONE A8
TO HIGH VOLTAGE OPTION
DAC CLOCK*
DAC DATA*
DAC STROBE
U111 HC240
U134 74HCT4094
C205 0.1UF
SLOW FILTER*
3mSEC*
1mSEC*
300uSEC*
PG.1 ZONE A5
PG.1 ZONE D8
T100
BVAC PAD
P1006
+6.5V
UNREGULATED 6.5V TO DIGITAL BOARD
+C115 10,000UF
CR109
CR106
CR108
U107 7805
U106 7815
U108 79M15
+C117 1500UF
+C121 10UF
+C114 2200
+C123 10UF
+C108 2200
+C122 10UF
+15V
-15V
TP101
PG.2 ZONE B7
J1001
J1002
F100
S100 230V
115V
S101
OFF
ON
POWER SUPPLY
TO DIGITAL BOARD
P1005 +5VDS
P1005 INTERLOCK SAFE*
P1005 DIG GND2
P1005 CA. LOCK*3
S102
LOCKED
UNLOCKED
P1005 MEASUREMENT COMPLETE
P1005 TRIGGER IN
J1021
P1021
DIG GND
J1013
J1012
REAR PANEL
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
TITLE
SCHEMATIC,ANALOG BOARD
POWER SUPPLY AND COMMUNICATION
SIZE D
MODEL 486
NO 486-106
ECO
REV D1
DRAWN MAH
APPROVED
DATE 3/18/90
SHT 3 OF 3


3mSEC*
1mSEC*
300uSEC*
PG.3 ZONE C1
1E3
ZERO CHECK*
1E4
1E5
1E6
1E7
1E8
J1008
TO REAR PANEL
INPUT HI
L102
J1018
K110
K104
K105
K106
K107
K108
K109
C126 .01UF
R145 1K
C137 3300PF
R148 11K
C131 330PF
R134 100K
C135 100PF
R149 1.1M
C145 22PF
R153 10M
C148 10PF
R159 110M
C158 3.3P
R171 1G
R226 100K
R198 50K
R195 150K
Q119
C159 10PF
R193 10M
C147 22PF
R194 220K
R191 10
U142 AD549L
C198 0.1UF
R213 182
VR104 6.44V VR105 6.44V
R215 10
+15V
R231 10K
SLOW FILTER*
U145
C195 0.1UF
R220 10
-15V
+5VA
LOW PASS SLOW*
T101
230/115
115/NEUTRAL
115
NEUTRAL
PRIMARY SHIELD
250 VAC
250 VAC*
17 VAC
B GND
17 VAC*
PG.4 ZONE A8,B8
PG.3 ZONE B8,A8
PG.2 ZONE A1 +6.4V
PG.2 ZONE B7 +15V
PG.2 ZONE B7 -15V
PG.2 ZONE B7 +5VA
PG.2 ZONE B7
R188 18.6K
R192 15K
CAL
REF*
U144
DG411
ZERO*
ZERO
SIG*
PG.3 ZONE D1
R214 301
R211 100
R208 3K
R206 909
U146
LF411A
C190 .68UF
C191 .33
R207 10K
LT1012
U147
CR117
R197 1.5K
R189 1.5K
R210 47
C172 100PF
R227 15
C196 0.1UF
R203 1K
*R203 IS A FUSIBLE RESISTOR.
U132
A/D INPUT
TP105
PG.2 ZONE D8
OUTPUT HI
OUTPUT LO
NC
J1024
TO REAR PANEL
J1009
J1010
L103
C218 100PF
C219 100PF
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
TITLE
SCHEMATIC,ANALOG BOARD
(INPUT AMPLIFIER,FILTER,MUX)
SIZE D
MODEL 487
NO 487-106
ECO
REV D1
DRAWN MAH
APPROVED
DATE 3/12/90
SHT 1 OF 4


PG.1 ZONE C1
A/D INPUT
CB ENABLE
UNUSED GATES
FAST FINAL SLOPE
CB/FINAL SLOPE
SYNC'ED BALANCE
END FINAL SLOPE
TP104
TP102 INTEGRATOR
TP107 AGND
C/B COMP
C/B CLOCK
SYNC CLOCK
BALANCE
DISCHARGE*
20ns
ABORT
FINAL SLOPE/CB
FAST FINAL
48KHZ/1.5KHZ
ANALOG STROBE
Q'S OUT
ANALOG CLOCK
Q'S IN
PG.3 ZONE A4
PG.3 ZONE D1
SYNC CLOCK (384KHZ,2.6uS,40% DUTY)
C/B CLOCK (48KHZ,25% DUTY)
96KHZ
1.5KHZ
3.84MHZ
A/D COUNTS*
6.4V REFERENCE
+6.4V
PG.1 ZONE C4
PG.3 ZONE C5
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
SCHEMATIC,ANALOG BOARD
(ANALOG TO DIGITAL CONVERTER)
SIZE D
MODEL 487
NO 487-106
ECO
REV D1
DRAWN MAH
APPROVED
DATE 3/12/90
SHT 2 OF 4


ANALOG STROBE
ANALOG CLOCK
ANALOG DATA
A/D COUNTS*
OPTOISOLATORS
POWER SUPPLY
DAC CLOCK*
DAC DATA*
DAC STROBE
ANALOG CLOCK
ANALOG STROBE
SIG*
REF*
ZERO*
FAST FINAL
FINAL SLOPE/CB
ABORT
48KHZ/1.5KHZ
Q'S IN
Q'S OUT
LOW PASS SLOW*
SLOW FILTER*
3mSEC*
1mSEC*
300uSEC*
+OVI/-OUT
2mA/20uA
OPERATE*
500/50V
INTERLOCK SAFE*
DIG GND2
CAL LOCK*
LOCKED
UNLOCKED
MEASUREMENT COMPLETE
TRIGGER IN
REAR PANEL
TO DIGITAL BOARD
TO DIGITAL BOARD
UNREGULATED 6.5V TO DIGITAL BOARD
NEUTRAL
PRIMARY SHIELD
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
SCHEMATIC, ANALOG BOARD
(POWER SUPPLY AND COMMUNICATION)
487
487-106
D1
MAH
3/12/90
SHT 3 OF 4


PG.3 ZONE A4
DAC CLOCK*
DAC DATA*
DAC STROBE
PG.3 ZONE C4
V151 AD7846
V153 74HCT4094
V152 74HCT4094
U149 AD586
Q120
Q114
Q115
R235 10K
R240 100K
C170 0.1UF
C218 1UF
C226 .01UF
R237 20K
R236 20K
R241 20
C225 0.1UF
R239 10K
R199 10
R132 30.51K
C175 0.1UF
C224 10UF
C197 0.1UF
C220 10UF
C223 0.1UF
C222 10UF
C22 0.1UF
+800VB
R106 10K
R107 1M
R113 1M
C107 .01UF
Q101
Q105
Q103
2N3904
R108 100
CR110 1N914
R151 100
R152 10K
POWER AMP
CR115 1N914
R155 820
C154 390PF
CR116 1N914
R168 432K
CR114 1N914
CR113 1N914
JR102 6.44V
U119 LT1012
C146 0.1UF
C157 0.1UF
20 uA CURRENT LIMIT
+5VD
R133 1K
PG.3 ZONE D8
AT101 PS2501 1
I-LIMIT*
CURRENT LIMIT STATUS
DIG GND3
W100
OPTION*
HIGH IMPEDANCE AMP
U110 LT1012
CR112 1N914
CR111 1N914
C125 1500PF
R129 1K
VR101 6.44V
CR101
R225 1K
CR107
Q106
Q107
R125 20K
R126 619
1 MA CURRENT SOURCE
0 TO 500V 10mV/CNT OR 0 TO 50V 1mV/CNT
2mA/20uA
+OUT/-OUT
OPERATE*
PG.3 ZONE B1
TO REAR PANEL
J1026
J1014
J1015
L104
L105
K100 OPERATE RELAY
K102
K101
CURRENT LIMIT RELAY
POLARITY RELAY
C220 100PF
C221 100PF
250 VAC
250 VAC*
CR100
C106 .01UF
C103 33UF
R104 100
R101 3.9K
Q102
Q100
R103 2.2M
R102 2.2K
C105 .05UF
C104 .05UF
CR105
PG.1 ZONE D2
17 VAC
17 VAC*
8 GND
CR104
CR102
C102 10UF
C192 .02UF
R115 4.7K
R116 10K
JR106 30V
DP100
U100 78L15
U102 78L05
C101 2200
C100 2200
C112 10UF
C111 10UF
C110 10UF
U101 7915
-24VU
+24VU
+15VB
-15VB
+5VB
+5VA
R127 5.6K
C116 150PF
R117 2M
R109 20K
RANGE RELAY
K103
500/50V
R110 220K
R112 2191
R111 1K
C113 390PF
AMPLIFIER FEEDBACK
KEITHLEY
KEITHLEY INSTRUMENTS INC.
CLEVELAND, OHIO 44139
TITLE
SCHEMATIC,ANALOG BOARD
(HIGH VOLTAGE SOURCE, 487 ONLY)
SIZE D
MODEL 487
NO 487-106
ECO
REV D1
DRAWN MRH
APPROVED
DATE 3/12/90
SHT 4 OF 4

MODEL 486 MISCELLANEOUS, PARTS LIST

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
	SHIELD, ANALOG BOTTOM	428-317B
	PUSHBUTTON, POWER	428-318-1B
	BEZEL, REAR	428-303B
	MOUNTING EAR	428-328C
	HANDLE	428-329C
	FOOT,RUBBER	FE-6
	GASKET	GA-21
	IEEE MTG HARDWARE	CS-378
	FRONT PANEL	428-302D
	SHIELD, DIGITAL	428-307A
	KNOB	428-310A
	PUSHROD	428-315C
	CLIP, ALLIGATOR	AC-10
	LUG	LU-90
	COVER	428-306C
	FOOT, EXTRUDED	FE-22A
	FOOT	428-319A
	GASKET	GA-28
	SC-137-6	
	OVERLAY, FRONT PANEL	486-304C
	SHIELD, ANALOG TOP	486-306A
	CONNECTOR	CS-276
	LUG	LU-88
	SHIELD, DISPLAY	428-305
	CHASSIS	486-309
	CONTACT, RFI	486-312A
	DISPLAY LENS	487-306C
	CAP	CAP-28-1
	BEZEL TO CHASSIS TRUARC RETAINING RING	FA-233-1A
	BEZEL TO CHASSIS CAPTIVE PANEL SCREW	FA-232-1A
	LINE CORD	CO-7
C218,C19	CAP,100PF,10%,1000V,CERAMIC	C-64-100P
J1001	LINE FILTER	LF-2
J1008	CONNECTOR 3 LUG TRIAX	CS-630
J1009	BINDING POST	BP-11-2
J1010	BINDING POST	BP-11-0
J1011	BINDING POST	BP-11-5
J1012,1013	CONNECTOR,BNC	CS-249
L102,103	CHOKE	CH-51
P1002	HOUSING, CONNECTOR	CS-287-5
P1018	CONNECTOR	CS-236
P1024	CONNECTOR, HOUSING	CS-638-3

MODEL 487 MISCELLANEOUS, PARTS LIST

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
	SHIELD, ANALOG TOP	486-306A
	BEZEL, REAR	428-303B
	CONTACT, RFI	486-312A
	FOOT	428-319A
	OVERLAY, FRONT PANEL	487-304B
	HANDLE	428-329C
	DISPLAY LENS	487-306C
	PUSHBUTTON, POWER	428-318-1B
	FOOT, EXTRUDED	FE-22A
	FOOT,RUBBER	FE-6
	FRONT PANEL	428-302D
	SHIELD, DIGITAL	428-307A
	KNOB	428-310A
	PUSHROD	428-315C
	SHIELD, ANALOG BOTTOM	428-317B
	CONNECTOR	CS-276
	LUG	LU-88
	GASKET	GA-28
	COVER	428-306C
	CLIP, ALLIGATOR	AC-10
	MOUNTING EAR	428-328C
	CHASSIS ASS'Y	487-308A
	SHIELD, DISPLAY	428-305
	CHASSIS	487-309
	CAP	CAP-28-1
	GASKET	GA-21
	IEEE MTG HARDWARE	CS-378
	CABLE CLAMP	CC-62
	LINE CORD	CO-7
C218..221	CAP,100PF,10%,1000V,CERAMIC	C-64-100P
J1001	LINE FILTER	LF-2
J1008	CONNECTOR 3 LUG TRIAX	CS-630
J1009,1014	BINDING POST	BP-11-2
J1010,1015	BINDING POST	BP-11-0
J1011	BINDING POST	BP-11-5
J1012,1013	CONNECTOR,BNC	CS-249
J1016	CONNECTOR, 3 PIN MALE	CS-659
L102..105	CHOKE	CH-51
P1002	HOUSING, CONNECTOR	CS-287-5
P1017	LUG	LU-90
P1018	CONNECTOR	CS-236
P1021		CS-638-6
P1024,1026	CONNECTOR, HOUSING	CS-638-3

APPENDIX A
Device-dependent Command Summary

Table A-1. Device-dependent Command Summary

Mode	Command	Description	Para.
Display Intensity	A0	Normal display	4.2.1
	A1	Dim display	
	A2	Turn display off	
Reading Source	B0	Readings from A/D	4.2.2
	B1	Single reading from data store	
	B2	All readings from data store	
	B3	Maximum reading from data store	
	B4	Minimum reading from data store	
Zero Check and Correct	C0	Disable zero check	4.2.3
	C1	Enable zero check	
	C2	Enable zero check and perform zero correction	
Display	Da	Display up to 18 character (a) message	4.2.4
	D	Cancel display mode	
V/I Ohms	F0	Disable V/I ohms	4.2.5
	F1	Enable V/I ohms	
Data Format	G0	ASCII rdgs with prefix	4.2.6
	G1	ASCII rdgs without prefix	
	G2	ASCII rdgs and buffer locations with prefix	
	G3	ASCII rdgs and buffer locations without prefix	
	G4	Binary rdgs: IEEE Std 754 single-precision, bytes reversed for Intel CPUs	
	G5	Binary rdgs: IEEE Std 754 single-precision, bytes in normal order for Motorola CPUs	
	G6	Binary rdgs: counts and exponent, bytes reversed for Intel CPUs	
	G7	Binary rdgs: counts and exponent, bytes in normal order for Motorola CPUs	
Hit Control	H1	Hit DISPLAY INTENSITY key	4.2.7
	H2	Hit LOCAL key	
	H3	Hit SHIFT key	
	H4	Hit MENU key	
	H5	Hit ZERO CHECK key	
	H6	Hit FILTER key	
	H7	Hit RANGE V key	
	H8	Hit REL key	
	H9	Hit RANGE A key	
	H10	Hit SETUP key	
	H11	Hit TRIGGER key	

Device-dependent Command Summary (Cont.)

Mode	Command	Description	Para.
Hit Control (cont.)	H12	Hit OPERATE key (487)	4.2.7
	H13	Hit PRESET key (487)	
	H14	Hit ◀	
	H15	Hit ▶	
	H16	Hit Rotary Knob counterclockwise	
	H17	Hit Rotary Knob clockwise	
Self-Test	J0	Perform ROM/RAM self-test	4.2.8
	J1	Perform display and ROM/RAM self-test	
EOI and Bus Hold-off	K0	Enable EOI and bus hold-off on X	4.2.9
	K1	Disable EOI, enable bus hold-off on X	
	K2	Enable EOI, disable bus hold-off on X	
	K3	Disable both EOI and bus hold-off on X	
Default Conditions or Calibration	L0	Return to factory default conditions and save (L1)	4.2.10
	L1	Save present states as default conditions	
	L2	Return to saved default conditions	
	L3,v	Calibrate present measurement range using "v"; v = –2E–3 to +2E–3 amps	
	L4	Calibrate zero on present voltage source range (Model 487 only)	
	L5	Calibrate full scale on present voltage source range (Model 487 only)	
	L6	Prepare to calibrate present voltage source range (Model 487 only)	
SRQ	M0	Disable SRQ	4.2.11
	M1	Reading overflow	
	M2	Data store full	
	M4	Data store half full	
	M8	Reading done	
	M16	Ready	
	M32	Error	
	M128	Voltage Source Error (Model 487 only)	
Data Store	N0	Arm data store; wrap around operation	4.2.12
	Nn	Arm data store; set buffer size "n" where n = 1 to 512	
Operate	O0	Place voltage source in standby	4.2.13
	O1	Place voltage source in operate	
Filters	P0	Disable digital and analog filters	4.2.14
	P1	Enable digital filter; disable analog filter	
	P2	Disable digital filter; enable analog filter	
	P3	Enable digital and analog filters	
Interval	Q0	175msec (factory default)	4.2.15
	Qn	Set to "n" seconds. n = 0.010sec to 999.999sec	
Range	R0	Enable autorange	4.2.16
	R1	Select 2nA range	
	R2	Select 20nA range	
	R3	Select 200nA range	
	R4	Select 2µA range	
	R5	Select 20µA range	
	R6	Select 200µA range	

Device-dependent Command Summary (Cont.)

Mode	Command	Description	Para.
Range (cont.)	R7	Select 2mA range	4.2.16
	R8	No range	
	R9	No range	
	R10	Disable autorange	
Integration	S0	Fast integration; 1.6msec at 4-1/2 digit resolution	4.2.17
	S1	Line cycle integration; 16.67msec (60Hz) or 20msec at 5-1/2 digit resolution	
Trigger	T0	Multiple on Talk	4.2.18
	T1	One-shot on Talk	
	T2	Multiple on GET	
	T3	One-shot on GET	
	T4	Multiple on X	
	T5	One-shot on X	
	T6	Multiple on External Trigger	
	T7	One-shot on External Trigger	
	T8	Multiple on Operate (487)	
	T9	One-shot on Operate (487)	
Status	U0	Send machine status word	4.2.19
	U1	Send error status word	
	U2	Send model number and firmware revision	
	U3	Send calibration value	
	U4	Send interval	
	U5	Send delay	
	U6	Send relative value for current	
	U7	Send relative value for V/I ohms	
	U8	Send voltage source value (487)	
	U9	Send voltage source error status word (487)	
Voltage Source (487)	Vn,r,l	Specify voltage source level "n" in volts, range "r" and limit "l" n: –505 to +505 r: 0 = 50V range; 1 = 500V range l: 0 = 20µA limit; 1 = 2mA limit	4.2.20
Delay	Wn	Delay trigger "n" seconds; n = 0 to 999.999sec	4.2.21
Execute	X	Execute other device-dependent commands	4.2.22
Terminator	Y0	CR LF	4.2.23
	Y1	LF CR	
	Y2	CR	
	Y3	LF	
	Y4	None	
Relative	Z0	Disable relative	4.2.24
	Z1	Enable relative using present reading as baseline	
	Z2,V	Enable relative using "v" as baseline; v = –2E–3 to +2E–3 amps for current, v = 0Ω to 50.5E16Ω for V/I ohms	
	Z3	Enable relative using the baseline previously defined	

APPENDIX B
Interface Function Codes

The interface function codes, which are part of the IEEE-488 standards, define an instrument's ability to support various interface functions and should not be confused with programming commands found elsewhere in this manual. The interface function codes for the Model 486/487 are listed in Table B-1. The codes define Model 486/487 capabilities as follows:

SH (Source Handshake Function) — SH1 defines the ability of the instrument to initiate the transfer of message/data over the data bus.

AH (Acceptor Handshake Function) — AH1 defines the ability of the instrument to guarantee proper reception of message/data transmitted over the data bus.

T (Talker Function) — The ability of the instrument to send data over the bus to other devices is provided by the T function. Instrument talker capabilities (T5) exist only after the instrument has been addressed to talk or when it is placed in talk-only.

L (Listener Function) — The ability for the instrument to receive device-dependent data over the bus from other devices is provided by the L function. Listener capabilities (L4) of the instrument exist only after it has been addressed to listen.

SR (Service Request Function) — SR1 defines the ability of the instrument to request service from the controller.

RL (Remote-Local Function) — RL1 defines the ability of the instrument to be placed in the remote or local modes.

PP (Parallel Poll Function) — The instrument does not have parallel polling capabilities (PP0).

DC (Device Clear Function) — DC1 defines the ability of the instrument to be cleared (initialized).

DT (Device Trigger Function) — The Model 428 has no device trigger capability (DT0).

C (Controller Function) — The instrument does not have controller capabilities (C0).

TE (Extended Talker Function) — The instrument does not have extended talker capabilities (TE0).

LE (Extended Listener Function) — The instrument does not have extended listener capabilities (LE0).

E (Bus Driver Type) — The instrument has open-collector bus drivers (E1).

Table B-1. Model 486/487 Interface Function Codes

Code	Interface Function
SH1	Source Handshake capability
AH1	Acceptor Handshake capability.
T5	Talker (basic talker, serial poll, talk-only, unaddressed to talk on LAG)
L4	Listener (basic listener, unaddressed to listen on TAG)
SR1	Service Request capability
RL1	Remote/Local capability
PP0	No Parallel Poll capability
DC1	Device Clear capability
DT1	Device Trigger capability
C0	No Controller capability
E1	Open Collector Bus Drivers
TE0	No Extended Talker capabilities
LE0	No Extended Listener capabilities

APPENDIX C
ASCII Character Codes and IEEE-488 Multiline Interface Command Messages

Decimal	Hexadecimal	ASCII	IEEE-488 Messages*
0	00	NUL	
1	01	SOH	GTL
2	02	STX	
3	03	ETX	
4	04	EOT	SDC
5	05	ENQ	PPC
6	06	ACK	
7	07	BEL	
8	08	BS	GET
9	09	HT	TCT
10	0A	LF	
11	0B	VT	
12	0C	FF	
13	0D	CR	
14	0E	SO	
15	0F	SI	
16	10	DLE	
17	11	DC1	LLO
18	12	DC2	
19	13	DC3	
20	14	DC4	DCL
21	15	NAK	PPU
22	16	SYN	
23	17	ETB	
24	18	CAN	SPE
25	19	EM	SPD
26	1A	SUB	
27	1B	ESC	
28	1C	FS	
29	1D	GS	
30	1E	RS	
31	1F	US	

* Message sent or received with ATN true.

Decimal	Hexadecimal	ASCII	IEEE-488 Messages*
32	20	SP	MLA 0
33	21	!	MLA 1
34	22	"	MLA 2
35	23	#	MLA 3
36	24	$	MLA 4
37	25	%	MLA 5
38	26	&	MLA 6
39	27	'	MLA 7
40	28	(	MLA 8
41	29	)	MLA 9
42	2A	*	MLA 10
43	2B	+	MLA 11
44	2C	'	MLA 12
45	2D	–	MLA 13
46	2E	.	MLA 14
47	2F	/	MLA 15
48	30	0	MLA 16
49	31	1	MLA 17
50	32	2	MLA 18
51	33	3	MLA 19
52	34	4	MLA 20
53	35	5	MLA 21
54	36	6	MLA 22
55	37	7	MLA 23
56	38	8	MLA 24
57	39	9	MLA 25
58	3A	:	MLA 26
59	3B	;	MLA 27
60	3C	<	MLA 28
61	3D	=	MLA 29
62	3E	>	MLA 30
63	3F	?	UNL

* Message sent or received with ATN true. Numbers shown represent primary address resulting in MLA (My Listen Address).

Decimal	Hexadecimal	ASCII	IEEE-488 Messages*
64	40	@	MTA 0
65	41	A	MTA 1
66	42	B	MTA 2
67	43	C	MTA 3
68	44	D	MTA 4
69	45	E	MTA 5
70	46	F	MTA 6
71	47	G	MTA 7
72	48	H	MTA 8
73	49	I	MTA 9
74	4A	J	MTA 10
75	4B	K	MTA 11
76	4C	L	MTA 12
77	4D	M	MTA 13
78	4E	N	MTA 14
79	4F	O	MTA 15
80	50	P	MTA 16
81	51	Q	MTA 17
82	52	R	MTA 18
83	53	S	MTA 19
84	54	T	MTA 20
85	55	U	MTA 21
86	56	V	MTA 22
87	57	W	MTA 23
88	58	X	MTA 24
89	59	Y	MTA 25
90	5A	Z	MTA 26
91	5B	[	MTA 27
92	5C	\	MTA 28
93	5D	]	MTA 29
94	5E	∩	MTA 30
95	5F	—	UNL

* Message sent or received with ATN true. Numbers shown are primary address resulting in MTA (My Talk Address).

Decimal	Hexadecimal	ASCII	IEEE-488 Messages*
96	60	`	MSA 0,PPE
97	61	a	MSA 1,PPE
98	62	b	MSA 2,PPE
99	63	c	MSA 3,PPE
100	64	d	MSA 4,PPE
101	65	e	MSA 5,PPE
102	66	f	MSA 6,PPE
103	67	g	MSA 7,PPE
104	68	h	MSA 8,PPE
105	69	i	MSA 9,PPE
106	6A	j	MSA 10,PPE
107	6B	k	MSA 11,PPE
108	6C	l	MSA 12,PPE
109	6D	m	MSA 13,PPE
110	6E	n	MSA 14,PPE
111	6F	o	MSA 15,PPE
112	70	p	MSA 16,PPD
113	71	q	MSA 17,PPD
114	72	r	MSA 18,PPD
115	73	s	MSA 19,PPD
116	74	t	MSA 20,PPD
117	75	u	MSA 21,PPD
118	76	v	MSA 22,PPD
119	77	w	MSA 23,PPD
120	78	x	MSA 24,PPD
121	79	y	MSA 25,PPD
122	7A	z	MSA 26,PPD
123	7B	{	MSA 27,PPD
124	7C	|	MSA 28,PPD
125	7D	}	MSA 29,PPD
126	7E	~	MSA 30,PPD
127	7F	DEL	

* Message sent or received with ATN true. Numbers represent secondary address values resulting in MSA (My Secondary Address).

APPENDIX D
Controller Programs

The following programs have been supplied as a simple aid to the user and are not intended to suit specific needs. Each program allows you to send a device-dependent command string to the instrument and obtain and display a string from the instrument.

Programs for the following controllers are included:

- A BASIC program for an IBM PC/XT/AT with a Capital Equipment Corporation PC<>488 Interface (Keithley Model PC-488-CEC IEEE-488 Interface Card).
- A program written with the ASYST software package (available from Keithley Instruments) for an IBM PC/XT/AT with a Capital Equipment Corporation PC<>488 Interface.
- A BASIC program for an IBM PC/XT/AT with IOtech Driver488 Software.
- A BASIC program for an IBM PC/XT/AT with a National GPIB PC Interface.
- A BASIC program for a Hewlett-Packard Model 9000 Series 200/300 computer.

NOTE

To make sure that the instrument is in a proper trigger mode (to avoid bus hang up), it is recommended that factory initialization be performed before running any of the following programs.

IBM PC/XT/AT with Capital Equipment Corporation PC<>488 Interface (Keithley PC-488-CEC)

Introduction

General information about controlling a Model 486/487 with an IBM PC/XT/AT computer and Capital Equipment Corporation PC<>488 interface is given here. Refer to the CEC PC<>488 Programming and Reference Manual for complete information.

Initializing the System

The first step in any program is to initialize the system using the INITIALIZE routine. This routine sets the primary IEEE-488 bus address of the PC<>488, specifies the type of controller to be used, and sends an interface clear (IFC) to the other devices on the bus.

After booting up the IBM using DOS and entering BASICA, the statements of program 1 can be used at the start of any program to initialize the system:

Line 30 sets the address of the PC<>488 to 21, however, any other valid address could be used as long as it does not conflict with the address of any other device on the bus.

Interface Basic Programming Statements

This paragraph covers the PC<>488 statements that are essential to Model 486/487 operation. A partial list of programming statements is contained in Table D-1. The IBM BASIC CALL statement is used to execute the desired action. Before a CALL routine can be used, BASIC needs to know the offset address of the routine. In the table, the first statement of each programming sequence defines the offset address of the CALL routine.

Example Program

The following program sends a command string from an IBM PC/XT/AT computer to the Model 486/487 and displays the response on the CRT. The computer must be equipped with a CEC interface card and DOS 2.0 (or later revision) operating system.

Directions

1. Using the front panel MENU key, set the primary IEEE-488 address of the Model 486/487 to 22.
2. With the power off, connect the Model 486/487 to the IEEE-488 interface card installed in the IBM computer.
3. Type in BASICA on the computer keyboard to get into interpretive BASIC language.
4. Enter the lines of Program 2 using the return key after each line.
5. Run the program and type in the desired command string at the ENTER COMMAND STRING? prompt. For example, to view the instrument model number and firmware revision, type in U2X and press the return key. The Model 486/487 firmware revision will then appear on the computer display. A single reading will appear for DDCs that have no response.

PROGRAM		COMMENTS
10	DEF SEG=&HC400	' Memory offset.
20	INITIALIZE=0	' Offset address of routine
30	MY.ADDRESS%=21	' Set PC<>488 address.
40	CONTROLLER%=0	' Set for system control.
50	CALL INITIALIZE (MY.ADDRESS%, CONTROLLER%)	' Execute INITIALIZE routine.

Program 1

```
PROGRAM                                          COMMENTS
10   DEF SEG=&HC400                              ' Memory address
20   INITIALIZE=0                                ' Define call offsets
30   SEND=9:ENTER=21
40   MY.ADDRESS%=21                              ' Set PC<>488 address
50   INST.ADDRESS%=22                            ' Set 486/487 address
60   CONTROLLER%=0                               ' Set for system control
70   CALL INITIALIZE (MY.ADDRESS%,               ' Initialize system
     CONTROLLER%)
80   LINE INPUT "ENTER COMMAND                   ' Prompt for string
     STRING:";CMD$
90   CALL SEND (INST.ADDRESS%,CMD$,              ' Send command string
     STATUS%)
100  RESPONSE$=SPACE$(80)                        ' Make room for data
110  CALL ENTER (RESPONSE$,LENGTH%,              ' Get response from 486/487
     INST.ADDRESS%,STATUS%)
120  PRINT RESPONSE$                             ' Display response
130  GOTO 80                                      ' Repeat
140  END
```

Program 2

Table D-1. BASIC Statements Necessary to Send Bus Commands

Action	PC<>488 Statements
Transmit command string (CMD$) to device 22.	SEND=9 ADDRESS%=22 CALL SEND(ADDRESS%,CMD$,STATUS%)
Obtain string from device 22.	ENTER=21 ADDRESS%=22 RESPONSE$=SPACE$(50) CALL ENTER(RESPONSE$,LENGTH%,ADDRESS%,STATUS%)
Send GTL to device 22.	TRANSMIT=3 CMD$="LISTEN 22 GTL" CALL TRANSMIT(CMD$,STATUS%)
Send SDC to device 22.	TRANSMIT=3 CMD$="LISTEN 22 SDC" CALL TRANSMIT(CMD$,STATUS%)
Send DCL to all devices.	TRANSMIT=3 CMD$="LISTEN 22 DCL" CALL TRANSMIT(CMD$,STATUS%)
Send remote enable.	TRANSMIT=3 CMD$="REN LISTEN 22" CALL TRANSMIT(CMD$,STATUS%)
Serial poll device 22.	SPOLL=12 ADDRESS%=22 CALL SPOLL%(ADDRESS%,POLL%,STATUS%)

IBM PC/XT/AT with CEC PC<>488 Interface and ASYST Software Package

Introduction

ASYST contains data acquisition, analysis, and graphing software in three integrated modules. Minimum requirements for ASYST include: 512K RAM (640K recommended), math coprocessor, parallel port, hard drive, and DOS 2.0 (or later version) operating system.

For this example, an optional software module is required for IEEE-488 interfacing. The computer must also be equipped with a CEC interface card (PC<>488 Model 300 or 310, or 4x488).

The ASYST program listed here sends a command string from an IBM PC/XT/AT computer to the Model 486/487 and displays the response on the computer's CRT.

Directions

This procedure will help an ASYST user through the steps necessary for GPIB configuration, program entry, and program execution. Refer to the ASYST documentation for more detailed instructions.

1. Using front panel MENU, set the primary address of the Model 486/487 to 22.
2. With the power off, connect the Model 486/487 to the IEEE-488 interface card installed in the IBM computer.
3. Boot ASYST software from DOS. You will get an OK prompt.
4. Use the <F2> key to enter the Main Configuration Menu. In addition to the usual configuration requirements of ASYST, the GPIB must be configured.

   From the Overlay Configuration Menu, select overlays GPIB Master and Type 1 NEC GPIB Driver.

   From the GPIB Configuration Menu, select a bus number, board type (National GPIB-PC1 or GPIB-PC2 for ASYST 2.0, Capital – NEC uPD7210 model for ASYST 3.0), memory address (2B8), primary address (0), and interrupt line.

5. Save your changes and return to the OK prompt.
6. Use the command line editor (EDIT 486.DMO) to enter the following program. Save the program and exit the editor.
7. When prompted, load the program with the L key, or type LOAD 486.DMO from the OK prompt.
8. When the program loads properly, type MAIN from the OK prompt to start execution.
9. Type in the desired command string at the "Enter command string:" prompt. For example, to view the instrument model number and firmware revision, type in U2X and press the return key. The Model 486/487 firmware revision will then appear on the computer display. A single reading will appear for DDCs that have no response.
10. Type <Control-Break> to exit the program loop of 486.DMO and return to the OK prompt. The program-defined words can be removed from the ASYST dictionary by typing FORGET 486.

PROGRAM	COMMENTS
BUS.INIT	\ Initialize bus
SEND.INTERFACE.CLEAR	\ Take control of bus
REMOTE.ENABLE.ON	\ Allow remote operation
SYNCHRONOUS.GPIB	\ Make sure ASYST is in sync. mode
?GPIB.DEVICES	\ List controller parameters
22 GPIB.DEVICE 486	\ Set 486/487 address and name
EOI.ON	\ Enable end or identify
EOS.ON	\ Enable end of string terminator
10 EOS.CHARACTER	\ Use LF terminator
1000 TIMEOUT	\ Set timeout of 1sec
?GPIB.DEVICE	\ List 486/487 parameters
100 STRING COMMAND	\ Allocate 100 bytes for user input
100 STRING RESPONSE	\ Allocate 100 bytes for 486/487 response
: GET.INPUT	\ Definition for user input
CR ." ENTER COMMAND STRING:"	\ Prompt user
"INPUT COMMAND ":=	\ Get DDCs
;	
: MAIN	\ Definition for main program
BEGIN	\ Start loop
ME	\ Make controller current device
GET.INPUT	\ Get DDCs from user
486	\ Make 486/487 current device
COMMAND GPIB.WRITE	\ Send DDCs to 486/487
RESPONSE GPIB.READ	\ Get response
CR RESPONSE "TYPE	\ Display response
AGAIN	\ Return for more commands
;	

IBM PC/XT/AT or PS/2 with IOtech Driver488 Software

Introduction

Driver488 software is an IEEE-488 driver for IBM PC and compatible computers. When combined with an IEEE-488 interface board, the package can control devices from languages including BASIC, Pascal, Fortran, and C. Driver488 software is compatible with:

- IOtech GP488B or GP488/2 boards
- National Instruments GPIB-PC, PCII, PCIIA, or PCIII boards
- Capital Equipment #01000-00300 board
- IBM GPIB Adapter

The following GW-BASIC program sends a command string to the Model 486/487 and displays the instrument response on the CRT. The computer must be equipped with an IEEE-488 interface board, the DOS 3.00 (or later) operating system, and a language with DOS I/O capability. Driver488 controller software must be installed and configured as described in the instruction manual.

Directions

1. Using front panel MENU, set the primary address of the Model 486/487 to 22.
2. With power off, connect the Model 486/487 to the IEEE-488 interface installed in the IBM computer.
3. Type in GWBASIC on the computer and get into the Microsoft interpretive BASIC language.
4. Enter the lines below using the return key after each line.
5. Run the program and type in the desired command string at the COMMAND STRING prompt. For example, to view the instrument model number and firmware revision, type in U4X and press the return key. The Model 486/487 firmware revision will then appear on the computer display. A single reading will appear for DDCs that have no response.

PROGRAM		COMMENTS
10	OPEN "\DEV\IEEEOUT" FOR OUTPUT AS #1	' Open file for output
20	IOCTL#1, "BREAK"	' Reset
30	PRINT#1,"RESET"	
40	OPEN "\DEV\IEEEIN" FOR INPUT AS #2	' Open file for input
50	PRINT#1,"FILL ERROR"	' Enable SEQUENCE error detect
60	LINE INPUT "COMMAND STRING: ";A$	' Prompt for and get DDCs
70	IF LEN(A$)=0 THEN 130	' Check for null
80	PRINT #1,"OUTPUT 22;"+A$	' Address 486/487 to listen, send DDCs
90	PRINT #1,"ENTER 22"	' Address 486/487 to talk
100	LINE INPUT#2,B$	' Get response
110	PRINT B$	' Display response string
120	GOTO 60	' Repeat
130	END	

IBM PC/XT/AT with National GPIB PC Interface

Introduction

The following program sends a command string to the Model 486/487 from an IBM PC/XT/AT computer and displays the instrument reading string on the CRT. The computer must be equipped with the National GPIB PC Interface and the DOS 2.00 (or later revision) operating system. Interface software must be installed and configured as described in the instruction manual.

Directions

1. Using front panel MENU, set the primary address of the Model 486/487 to 22.
2. With the power off, connect the Model 486/487 to the IEEE-488 interface installed in the IBM computer.
3. Type in BASICA on the computer keyboard to get into the IBM interpretive BASIC language.
4. Place the interface software disk in the default drive, type LOAD"DECL", and press the return key.
5. Add the lines below to line 1-6 which are now in memory. Modify the address in lines 1 and 2, as described in the National instruction manual.
6. Run the program and type in the desired command string. For example, to view the instrument model number and firmware revision, type in U4X and press the return key. The Model 486/487 firmware revision will then appear on the computer display. A single reading will appear for DDCs that have no response

PROGRAM		COMMENTS
10	CLS	Clear screen.
20	NA$="GPIB0":CALL IBFIND(NA$,BRD0%)	Find board descriptor.
30	NA$="DEV1":CALL IBFIND(NA$,M486%)	Find instrument descriptor.
40	V%=22:CALL IBPAD(M486%,V%)	Set primary address to 22.
50	V%=&H102:CALL IBPOKE(BRD0%,V%)	Set timeouts.
60	V%=1:CALL IBSRE(BRD0%,V%)	Set REN true.
70	INPUT "COMMAND STRING";CMD$	Prompt for command.
80	IF CMD$="EXIT" THEN 150	See if program is to be halted.
90	IF CMD$="" THEN 70	Check for null input.
100	CALL IBWRT (M486%,CMD$)	Address 486/487 to listen, send string.
110	RD$=SPACE$(100)	Define reading input buffer.
120	CALL IBRD(M486%,RD$)	Address 486/487 to talk, get reading.
130	PRINT RD$	Display the string.
140	GOTO 70	Repeat.
150	V%=0:CALL IBONL(M486%,V%)	Close the instrument file.
160	CALL IBONL(BRD0%,V%)	Close the board file.
170	END	

Hewlett-Packard Model 9000 Series 200/300

Introduction

The following program sends a command string to the Model 486/487 from a Hewlett-Packard Model 9000 Series 200/300 computer and displays the response on the computer CRT. The computer must be equipped with HP BASIC 4.0.

Directions

1. Using front panel MENU, set the primary IEEE-488 address of the Model 486/487 to 22.
2. With the power off, connect the Model 486/487 to the IEEE-488 interface card installed in the HP computer.
3. Enter the lines in the program below, using the ENTER/RETURN key after each line.
4. Press the RUN key and type in the desired command string at the COMMAND STRING prompt. For example, to view the instrument model number and firmware revision, type in U4X and press the ENTER/RETURN key. The Model 486/487 firmware revision will then appear on the computer display. A single reading will appear for DDCs that have no response.

```
10  DIM A$[50],B$[50]
20  REMOTE 722                          ! Place 486/487 in remote.
30  LINPUT "COMMAND STRING:",A$         ! Prompt for and input command.
40  OUTPUT 722;A$                       ! Address 486/487 to listen, send string.
50  ENTER 722;B$                        ! Address 486/487 to talk, input response.
60  PRINT B$                            ! Display response string.
70  GOTO 30                             ! Repeat
80  END
```

APPENDIX E
IEEE-488 Bus Overview

Introduction

Basically, the IEEE-488 bus is simply a communication system between two or more electronic devices. A device can be either an instrument or a computer. When a computer is used on the bus, it serves to supervise the communication exchange between all the devices and is known as the controller. Supervision by the controller consists of determining which device will talk and which device will listen. As a talker, a device will output information and as a listener, a device will receive information. To simplify the task of keeping track of the devices, a unique address number is assigned to each one.

On the bus, only one device can talk at a time and is addressed to talk by the controller. The device that is talking is known as the active talker. The devices that need to listen to the talker are addressed to listen by the controller. Each listener is then referred to as an active listener. Devices that do not need to listen are instructed to unlisten. The reason for the unlisten instruction is to optimize the speed of bus information transfer since the task of listening takes up bus time.

Through the use of control lines, a handshake sequence takes place in the transfer process of information from a talker to a listener. This handshake sequence helps ensure the credibility of the information transfer. The basic handshake sequence between an active controller (talker) and a listener is as follows:

1. The listener indicates that it is read to listen.
2. The talker places the byte of data on the bus and indicates that the data is available to the listener.
3. The listener, aware that the data is available, accepts the data and then indicates that the data has been accepted.
4. The talker, aware that the data has been accepted, stops sending data and indicates that data is not being, sent.
5. The listener, aware that there is no data on the bus, indicates that it is ready for the next byte of data.

Bus Description

The IEEE-488 bus, which is also frequently referred to a the GPIB (General Purpose Interface Bus), was designed as a parallel transfer medium to optimize data transfer without using an excessive number of bus lines. In keeping with this goal, the bus has only eight data lines that are used for both data and with most commands. Five bus management lines and three handshake lines round out the complement of bus signal lines.

A typical set up for controlled operation is shown in Figure E-1. Generally, a system will contain one controller and a number of other instruments to which the commands are given. Device operation is categorized into three operators: controller, talker and listener. The controller does what its name implies; it controls the instruments on the bus. The talker sends data while a listener receives data. Depending on the type of instrument, any particular device can be a talker only, a listener only or both a talker and listener.

There are two categories of controllers: system controller, and basic controller. Both are able to control other instruments, but only the system controller has the absolute authority in the system. In a system with more than one controller, only one controller may be active at any given time. Certain protocol is used to pass control from one controller to another.

The IEEE-488 bus is limited to 15 devices, including the controller. Thus, any number of talkers and listeners up to that limit may be present on the bus at one time. Although several devices may be commanded to listen simultaneously, the bus can have only one active talker, or communications would be scrambled.

A device is placed in the talk or listen state by sending an appropriate talk or listen command. These talk and listen commands are derived from an instrument's primary address. The primary address may have any value between 0 and 31, and is generally set by rear panel DIP switches or programmed in from the front panel of the instrument. The actual listen address value sent out over the bus is obtained by ORing the primary address with $20. For exam-

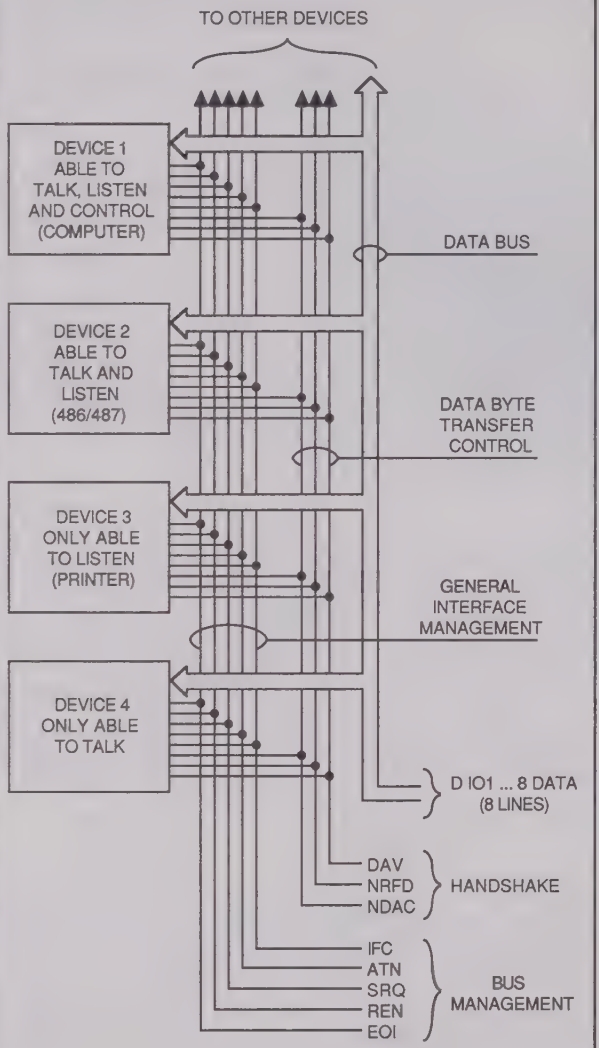


Figure E-1. IEEE-488 Bus Configuration

ple, if the primary address is 22 decimal ($16), the actual listen address is $36 ($36 = $16 + $20). In a similar manner, the talk address is obtained by ORing the primary address with $40. With the present example, the talk address derived from a primary address of 22 decimal would be $56 ($56 = $16 + $40).

The IEEE-488 standards also include another addressing mode called secondary addressing. Secondary addresses lie in the range of $60-$7F. Note, however, that many devices, including the Model 486/487, do not use secondary addressing.

Once a device is addressed to talk or listen, the appropriate bus transactions take place. For example: if the instrument is addressed to talk, it places its data string on the bus one byte at a time. The controller reads the information and the appropriate software can be used to direct the information to the desired location.

Bus Lines

The signal lines on the IEEE-488 bus are grouped into three different categories: data lines, management lines and handshake lines. The data lines handle bus data and commands, while the management and handshake lines ensure that proper data transfer and operation takes place. Each bus line is active low, with approximately zero volts representing a logic 1 (true). The following paragraphs describe the operation of these lines.

Data Lines

The IEEE-488 bus uses eight data lines that transfer data one byte at a time. DIO1 (Data Input/Output) through DIO8 (Data Input/Output) are the eight data lines used to transmit both data and multiline commands and are bidirectional. The data lines operate with low true logic.

Bus Management Lines

The five bus management lines help to ensure proper interface control and management. These lines are used to send the uniline commands.

ATN (Attention) — The ATN line is one of the more important management lines in that the state of this line determines how information on the data bus is to be interpreted.

IFC (Interface Clear) — As the name implies, the IFC line controls clearing of instruments from the bus.

REN (Remote Enable) — The REN line is used to place the instrument on the bus in the remote mode.

EOI (End or Identify) — The EOI is usually used to mark the end of a multi-byte data transfer sequence.

SRQ (Service Request) — This line is used by device when they require service from the controller.

Handshake Lines

The bus handshake lines that operate in an interlocked sequence. This method ensures reliable data transmission regardless of the transfer rate. Generally, data transfer will occur at a rate determined by the slowest active device on the bus.

One of the three handshake lines is controlled by the source (the talker sending information), while the remaining two lines are controlled by accepting devices (the listener or listeners receiving the information). The three handshake lines are:

DAV (DATA VALID) — The source controls the state of the DAV line to indicate to any listening devices whether or not data bus information is valid.

NRFD (Not Ready For Data) — The acceptor controls the state of NRFD. It is used to signal to the transmitting device to hold off the byte transfer sequence until the accepting device is ready.

NDAC (Not Data Accepted) — NDAC is also controlled by the accepting device. The state of NDAC tells the source whether or not the device has accepted the data byte.

The complete handshake sequence for one data byte is shown in Figure E-2. Once data is placed on the data lines, the source checks to see that NRFD is high, indicating that all active devices are ready. At the same time, NDAC should be low from the previous byte transfer. If these conditions are not met, the source must wait until NDAC and NRFD have the correct status. If the source is a controller, NRFD and NDAC must be stable for at least 100nsec after ATN is set true. Because of the possibility of a bus hang up, many controllers have time-out routines that display messages in case the transfer sequence stops for any reason.

Once all NDAC and NRFD are properly set, the source sets DAV low, indicating to accepting devices that the byte on the data lines is now valid. NRFD will then go low, and NDAC will go high once all devices have accepted the data. Each device will release NDAC at its own rate, but NDAC will not be released to go high until all devices have accepted the data byte.

The sequence just described is used to transfer both data, talk and listen addresses, as well as multiline commands. The state of the ATN line determines whether the data bus contains data, addresses or commands as described in the following paragraph.

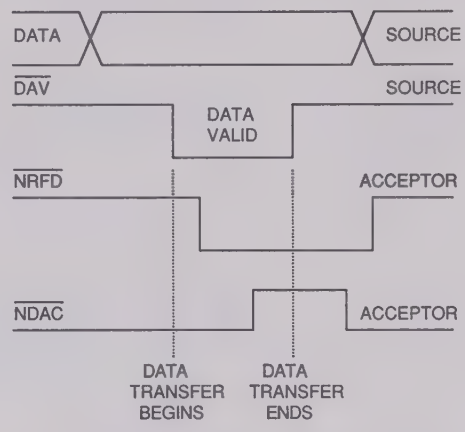


Figure E-2. IEEE-488 Handshake Sequence

Bus Commands

The instrument may be given a number of special bus commands through the IEEE-488 interface. This section briefly describes the purpose of the bus commands which are grouped into the following three categories.

1. Uniline Commands - Sent by setting the associated bus lines true. For example, to assert REN (Remote Enable), the REN line would be set low (true).
2. Multiline Commands - General bus commands which are sent over the data lines with the ATN line true (low).
3. Device-dependent Commands - Special commands whose meanings depend on device configurations; sent with ATN high (false).

These bus commands and their general purpose are summarized in Table E-1.

Uniline Commands

ATN, IFC and REN are asserted only by the controller. SRQ is asserted by an external device. EOI may be asserted either by the controller or other devices depending on the direction of data transfer. The following is a de-

Table E-1. IEEE-488 Bus Command Summary

Command Type	Command	State of ATN Line*	Comments
Uniline	REN (Remote Enable)	X	Sets up devices for remote operation.
	EOI	X	Marks end of transmission.
	IFC (Interface Clear)	X	Clears interface
	ATN (Attention)	Low	Defines data bus contents.
	SRQ	X	Controlled by external device.
Multiline Universal	LLO (Local Lockout)	Low	Locks out local operation.
	DCL (Device Clear)	Low	Returns device to default conditions.
	SPE (Serial Enable)	Low	Enables serial polling.
	SPD (Serial Poll Disable)	Low	Disables serial polling.
Addressed	SDC (Selective Device Clear)	Low	Returns unit to default conditions.
	GTL (Go To Local)	Low	Returns device to local.
Unaddressed	UNL (Unlisten)	Low	Removes all listeners from bus.
	UNT (Untalk)	Low	Removes any talkers from bus.
Device-dependent		High	Programs Model 486/487 for various modes.

* X = Don't Care

scription of each command. Each command is sent by setting the corresponding bus line true.

REN (Remote Enable) — REN is sent to set up instruments on the bus for remote operation. When REN is true, devices will be removed from the local mode. Depending on device configuration, all front panel controls except the LOCAL button (if the device is so equipped) may be locked out when REN is true. Generally, REN should be sent before attempting to program instruments over the bus.

EOI (End or Identify) — EOI is used to positively identify the last byte in a multi-byte transfer sequence, thus allowing data words of various lengths to be transmitted easily.

IFC (Interface Clear) — IFC is used to clear the interface and return all devices to the talker and listener idle states.

ATN (Attention) — The controller sends ATN while transmitting addresses or multiline commands.

SRQ (Service Request) — SRQ is asserted by a device when it requires service from a controller.

Universal Multiline Commands

Universal commands are those multiline commands that require no addressing. All devices equipped to implement such commands will do so simultaneously when the commands is transmitted. As with all multiline commands, these commands are transmitted with ATN true.

LLO (Local Lockout) — LLO is sent to the instrument to lock out the LOCAL key and thus all their front panel controls.

DCL (Device Clear) — DCL is used to return instruments to some default state. Usually, instruments return to their power-up conditions.

SPE (Serial Poll Enable) — SPE is the first step in the serial polling sequence which is used to determine which device has requested service.

SPD (Serial Poll Disable) — SPD is used by the controller to remove all devices on the bus from the serial poll mode and is generally the last command in the serial polling sequence.

Addressed Multiline Commands

Addressed commands are multiline commands that must be preceded by the device listen address before that instrument will respond to the command in question. Note that only the addressed device will respond to these commands. Both the commands and the address preceding it are sent with ATN true.

SDC (Selective Device Clear) — The SDC command performs essentially the same function as the DCL command except that only the addressed device responds. Generally, instruments return to their power-up default conditions when responding to the SDC command.

GTL (Go To Local) — The GTL command is used to remove instruments from the remote mode. With some instruments, GTL also unlocks front panel controls if they were previously locked out with the LLO command.

GET (Group Execute Trigger) — The GET command is used to trigger devices to perform a specific action that depends on device configuration (for example, take a reading). Although GET is an addressed command, many devices respond to GET without addressing.

Address Commands

Addressed commands include two primary command groups and a secondary address group. ATN is true when these commands are asserted. The commands include:

LAG (Listen Address Group) — These listen commands are derived from an instrument's primary address and are used to address devices to listen. The actual command byte is obtained by ORing the primary address with $20.

TAG (Talk Address Group) — The talk commands are derived from the primary address by ORing the address with $40. Talk commands are used to address devices to talk.

SCG (Secondary Command Group) — Commands in this group provide additional addressing capabilities. Many devices (including the Model 486/487) do not use these commands.

Unaddress Commands

The two unaddress commands are used by the controller to remove any talkers or listeners from the bus. ATN is true when these commands are asserted.

UNL (Unlisten) — Listeners are placed in the listener idle state by the UNL command.

UNT (Untalk) — Any previously commanded talkers will be placed in the talker idle state by the UNT command.

Device-dependent Commands

The purpose of the device-dependent commands will depend on the configuration of the instrument. Generally, these commands are sent as one or more ASCII characters that tell the device to perform a specific function.

The IEEE-488 bus actually treats these commands as data in that ATN is false when the commands are transmitted.

Command Codes

Command codes for the various commands that use the data lines are summarized in Figure E-3. Hexadecimal and the decimal values for the various commands are listed in Table E-2.

Figure E-3. Command Codes

D_7 D_6 D_5 D_4						X 0 0 0		X 0 0 1		X 0 1 0		X 0 1 1		X 1 0 0		X 1 0 1		X 1 1 0		X 1 1 1	
Bits	D_3 ↓	D_2 ↓	D_1 ↓	D_0 ↓	COLUMN → ROW ↓	0(A)	0(B)	1(A)	1(B)	2(A)	2(B)	3(A)	3(B)	4(A)	4(B)	5(A)	5(B)	6(A)	6(B)	7(A)	7(B)
	0	0	0	0	0	NUL		DLE		SP	0	0	16	@	0	P	16			p	
	0	0	0	1	1	SOH	GTL	DC1	LLO	!	1	1	17	A	1	Q	17	a		q	
	0	0	1	0	2	STX		DC2		"	2	2	18	B	2	R	18	b		r	
	0	0	1	1	3	ETX		DC3		#	3	3	19	C	3	S	19	c		s	
	0	1	0	0	4	EOT	SDC	DC4	DCL	$	4	4	20	D	4	T	20	d		t	
	0	1	0	1	5	ENQ	PPC*	NAK	PPU*	%	5	5	21	E	5	U	21	e		u	
	0	1	1	0	6	ACK		SYN		&	6	6	22	F	6	V	22	f		v	
	0	1	1	1	7	BEL		ETB		'	7	7	23	G	7	W	23	g		w	
	1	0	0	0	8	BS	GET	CAN	SPE	(	8	8	24	H	8	X	24	h		x	
	1	0	0	1	9	HT	TCT*	EM	SPD	)	9	9	25	I	9	Y	25	i		y	
	1	0	1	0	10	LF		SUB		*	10	:	26	J	10	Z	26	j		z	
	1	0	1	1	11	VT		ESC		+	11	;	27	K	11	[	27	k		{	
	1	1	0	0	12	FF		FS		,	12	<	28	L	12	\	28	l		:	
	1	1	0	1	13	CR		GS		–	13	=	29	M	13	]	29	m		}	
	1	1	1	0	14	SO		RS		.	14	>	30	N	14	^	30	n		~	
	1	1	1	1	15	SI		US		/	15	?	UNL	O	15	—	UNT	o		DEL	

ADDRESSED COMMAND GROUP (ACG)

UNIVERSAL COMMAND GROUP (UCG)

LISTEN ADDRESS GROUP (LAG)

TALK ADDRESS GROUP (TAG)

PRIMARY COMMAND GROUP (PCG)

SECONDARY COMMAND GROUP (SDC)

*PPC (PARALLEL POLL CONFIGURE). PPU (PARALLEL POLL UNCONFIGURE), AND TCT (TAKE CONTROL) NOT IMPLEMENTED BY THE INSTRUMENT,

NOTE: D_0 = DIO1 . . . D_7 = DIO8
X = DON'T CARE

Table E-2. Hexadecimal and Decimal Command Codes

Command	Hex Value	Decimal Value
GTL	01	1
SDC	04	4
GET	08	8
LLO	11	17
DCL	14	20
SPE	18	24
SPD	19	25
LAG	20-3F	32-63
TAG	40-5F	64-95
SGG	60-7F	96-127
UNL	3F	63
UNT	5F	95

Typical Command Sequences

For the various multiline commands, a specific bus sequence must take place to properly send the command. In particular, the correct listen address must be sent to the instrument before it will respond to addressed commands. Table E-3 lists a typical bus sequence for sending the addressed multiline commands. In this instance, the SDC command is being sent to the instrument. UNL is generally sent as part of the sequence to ensure that no other active listeners are present. Note that ATN is true for both the listen command and the SDC command byte itself.

Table E-4 gives a typical device-dependent command sequence. In this instance, ATN is true while the instrument is being addressed, but it is set high while sending the device-dependent command string.

IEEE Command Groups

Command groups supported by the Model 486/487 are listed in Table E-5. Device-dependent commands are not included in this list.

Table E-3. Typical Addressed Command Sequence

Step	Command	ATN State	Data Bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	0	36	54
3	SDC	Stays low	EOT	04	4
4		Returns high			

*Assumes primary address = 22.

Table E-4. Typical Device-dependent Command Sequence

Step	Command	ATN State	Data Bus		
			ASCII	Hex	Decimal
1	UNL	Set low	?	3F	63
2	LAG*	Stays low	0	36	54
3	Data	Set high	F	52	82
4	Data	Stays high	0	30	48
5	Data	Stays high	X	58	88

*Assumes primary address = 22.

Table E-5. IEEE Command Groups

HANDSHAKE COMMAND GROUP	
	NDAC = NOT DATA ACCEPTED
	NRFD = NOT READY FOR DATA
	DAV = DATA VALID
UNIVERSAL COMMAND GROUP	
	ATN = ATTENTION
	DCL = DEVICE CLEAR
	IFC = INTERFACE CLEAR
	REN = REMOTE ENABLE
	SPD = SERIAL POLL DISABLE
	SPE = SERIAL POLL ENABLE
ADDRESS COMMAND GROUP	
LISTEN:	LAG = LISTEN ADDRESS GROUP
	MLA = MY LISTEN ADDRESS
	UNL = UNLISTEN
TALK:	TAG = TALK ADDRESS GROUP
	MTA = MY TALK ADDRESS
	UNT = UNTALK
	OTA = OTHER TALK ADDRESS
ADDRESSED COMMAND GROUP	
	ACG = ADDRESSED COMMAND GROUP
	GTL = GO TO LOCAL
	SDC = SELECTIVE DEVICE CLEAR
STATUS COMMAND GROUP	
	RQS = REQUEST SERVICE
	SRQ = SERIAL POLL REQUEST
	STB = STATUS BYTE
	EOI = END

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SERVICE FORM

Model No. _____ **Serial No.** _____ **Date** _____

Name and Telephone No. _____

Company _____

List all control settings, describe problem and check boxes that apply to problem. _____

_____

_____

☐Intermittent ☐Analog output follows display ☐Particular range or function bad; specify _____
☐IEEE failure ☐Obvious problem on power-up ☐Batteries and fuses are OK
☐Front panel operational ☐All ranges or functions are bad ☐Checked all cables

Display or output (circle one)

☐Drifts ☐Unable to zero
☐Unstable ☐Will not read applied input
☐Overload

☐Calibration only ☐C of C required
☐Data required

(attach any additional sheets as necessary.)

Show a block diagram of your measurement system including all instruments connected (whether power is turned on or not). Also, describe signal source.

Where is the measurement being performed? (factory, controlled laboratory, out-of-doors, etc.)

_____

_____

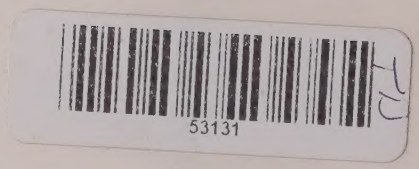
What power line voltage is used? _____ Ambient Temperature? _____ °F

Relative humidity? _____ Other? _____

Any additional information. (If special modifications have been made by the user, please describe.) _____

_____

Be sure to include your name and phone number on this service form.



KEITHLEY INSTRUMENTS

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